INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

Historical Changes in Climate and Lake Chad Surface Area in the Chad Basin

Ibrahim Baba Goni
Professor, Department of Geology, Maiduguri University, Maiduguri, Nigeria
Guillaume Favreau
Research Fellow, IRD, Hydrosciences, University of Montpellier, France
Alhaji Adam Zarma
Senior Lecturer, Department of Geology, Maiduguri University, Maiduguri, Nigeria

Abstract:
The Chad Basin has an area of about 2.5 Mkm2 and is considered the largest endoreic basin in the world. In the center of the basin is Lake Chad - a shallow lake (average ~1.5 m deep) with a surface area that has varied from ~25,000 km2 to ~2,000 km2 over the last 50 years. However, historically from Pleistocene to present time considerable changes in the surface area of the lake has occurred in response to climatic variability. During the Holocene (past ~12,000 yrs), the surface area of "Megalake Chad" was estimated to have reached a maximum of ~340,000 km2 during the humid period 8500-6300 BP. Several periods of dramatic shrinkage of the Lake were also shown to have occurred, with for instance, an almost complete drying up of the Lake in the middle of the 15th century. Over the last century, instrumental records of hydrological data are available in the region, which show variability in both rainfall and surface water conditions.
Present day shrinkage of the Lake was attributed to climatic variability and the induced environmental changes are accelerated by human demands on natural resources. Inter-basin surface water transfer is one option being canvassed to mitigate effects of the long-lasting shrinkage. However, because Lake Chad is an endoreic lake with no outflow to the ocean, the effect of injection of huge volume of water to its surface area needs to be fully understood. This is in order to minimise or avoid socio-economic impact that might have arise from excessive flooding of cultivated areas and/or villages, in addition to its impact on groundwater levels.

Keywords: *Climate change, Megalake Chad, Lake Chad, Groundwater, Anthropogenic factor, Socio-economic impact.*

1. Introduction

The Chad basin is the largest area of the inland drainage basin in Africa (Figure1), covering an area of ~2.34 to 2,5 Mkm2 (Oteze and Fayose, 1988; Leblanc, 2002; UNEP, 2004). The basin is named for its most conspicuous feature, Lake Chad. The basin covers 8% of the surface area of Africa, shared between the countries of Algeria, Cameroon, Central African Republic (CAR), Chad, Libya, Niger, Nigeria and Sudan (UNEP, 2004).

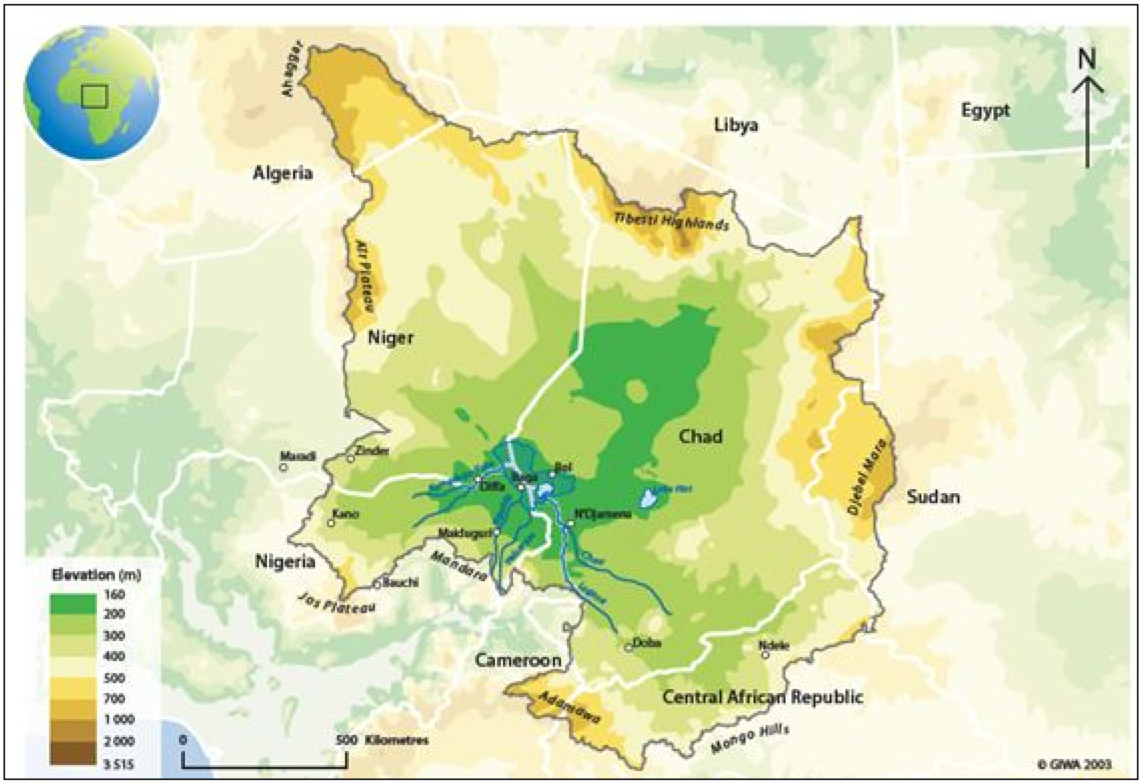

Figure 1: Main features of the Lake Chad Basin in Africa (from UNEP, 2004)

The Basin comprises of a number of transboundary waters that include three main aquifers (confined and unconfined) and a network of large catchment rivers, partly feeding the Lake. The Lake Chad itself experiences a close interaction between rainfall, evaporation, the generation of lateral inflow, groundwater leakage under the body of the Lake and human abstraction. These control the dynamics of the lake's fluctuations over time.

The Lake Chad's water supply is primarily from the Chari-Logone River (~330 000 km2), which provides approximately 90% to the southern pool and others the remaining 10% with the Komadugu-Yobe River (~120 000 km2) contributing to the northern pool. The water balance of the Lake is highly variable resulting in fluctuating open surface waters that have exhibited dramatic expansion and contraction over geologic and recent history. In the last decades the open water surface has reduced from approximately 25 000 km2 in 1963, to less than 2 000 km2 in the 1990s (Olivry et al. 1996, Grove 1996, Coe & Foley 2001). Although, for the 1998-2004 time period the Lake water surface has increased to about 3,000 km2 following increased rainfall.

About 37 M inhabitants live in the Lake Chad basin (UNEP, 2004) and depend for their livelihood on activities carried out in the lake and its active basin. It is therefore imperative to understand the dynamics of the basin in order to develop a strategy for sustainable utilization of the shared basin's water resources. This paper attempt to review at historical changes in Lake Chad surface are for better management of these highly climate-sensitive water resources in the Basin.

2. Climatic Review

The climatic conditions of an area are almost always directly linked to the landforms. In general, the tendency is that prolonged droughts are often associated with dune formation while wetter climates are characterised by fluvial, lacustrine and marine deposits. During times of decreased effective precipitation and given sufficient wind energy, there is often a tendency towards dune reactivation coupled with major shifts in surface-water hydrology and vegetation. Increases in effective moisture generally lead to dune stabilisation by herbaceous vegetation and also accompanied by alterations to the hydrological cycle and by changes in species composition of the dominant vegetation types. There is therefore a complex relationship between geomorphology, hydrology and vegetation characteristic of an area, and this form the basis for these elements providing proxy data for use in palaeoclimatic reconstruction. Therefore, wetter climates in the Chad basin region could be associated with larger surface area and higher volume of the Lake, while drought conditions will result in smaller Lake surface area.

2.1. Pleistocene

Stokes and Harrocks (1998) give period of deposition of the earlier phase of aeolian loessoid sediments in northern Nigeria that matches a period of increased aridity recognised in core sections off the northwest African coast based on increasing Zr/Rb ratios (Matthewson et al., 1995). This dry spell terminated at around 30 to 35 ka BP, but was rapidly followed by a further arid period, which is inferred by them to have lasted into the early Holocene. From the radiometric dating of lacustrine deposits, the periods between 30 and 22 ka BP is characterised by wet conditions with high lake levels (Nicholson, 1976) in the Lake Chad region. It is perhaps a period of major recharge to the groundwater as radiocarbon dating of the confined aquifers' water in this region, of around 24 ka BP (Edmunds et al. 1999) corresponds to this period. Also, noble gas data of confined aquifers' water in the Chad basin show that the waters were recharged under cooler conditions, about 6oC lower than the present water temperature (Figure2). Stable isotope data indicate that the waters were recharged under wetter conditions, with relatively depleted stable isotope compared to the present day recharge water. The δ2H and δ18O for confined aquifer palaeowaters have an average values of -45‰ and -6.5‰ respectively, while the present day recharged water has and average values of -25‰ and -4‰ for the δ2H and δ18O respectively (Figure 3).

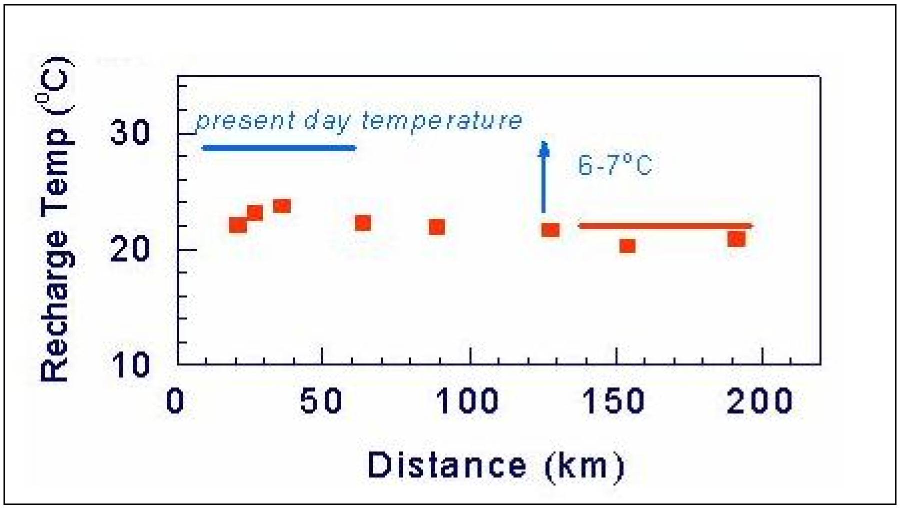

Figure 2: Noble gas estimate of palaeo and present day recharge temperatures for confined aquifers of the Chad basin (from Edmunds et al., 1999). Distance is from outcropping formations.

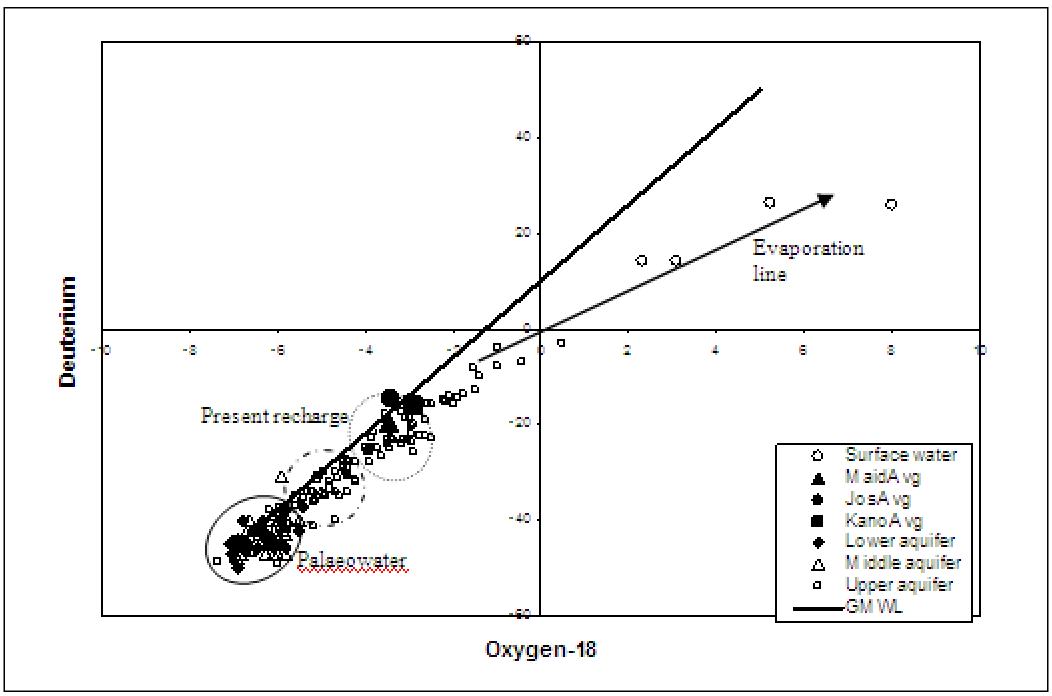

Figure 3: Stable isotope data for waters in the Chad basin region (Data from Goni, 2006)

Following a late Pleistocene lake phase (Rognon and Williams, 1977), the onset of more arid conditions was variable across the continent, but began about 20,000 years BP in most areas; maximum aridity was probably achieved between 18000 and 15000 years BP. The formation and marked expansion of aeolian and dunes along the southern margin of the present Sahara was a predominant feature of this episode. At the same time, the discharge of the Senegal was considerably reduced, and Lake Chad was probably almost totally dry, as were numerous basins and depressions in Niger, which subsequently contained lakes (Michel, 1973; Servant, 1973).

Numerous radiocarbon dates firmly establish the existence of the dune system in Chad from about 20,000 to 12,000 years BP. In Chad the dunal horizons are bracketed by lacustrine deposits radiometrically dated at 22,000 and 12,000 years BP. As lower temperature and hence decreased evaporation likely prevail, then, a decrease in rainfall along the tropical Saharan margins can be assumed. The desiccation of Lake Chad suggest drier conditions in Cameroon, Western Zaire (de Ploey, 1965), and southern Nigeria (Hurault, 1972, 1972; Hervieu, 1970, cited in Michel, 1973), being the source area of the rivers that feed the lake. At some time between 12,000 and 10,000 BP, rapid changes commenced in most of the Sahara, Sahel and the Sudan, where a lacustrine episode begins.

2.2. Holocene

The changes to lacustrine episode that begin between 12,000 and 10,000 BP in most of the Sahara, Sahel and the Sudan, attained a maximum from 10,000 to 8,000 years BP. Thiemeyer (2001) suggested, based on geomoprhological evidences, that the wetter climate resulted in the reappearance of Lake Chad, which rose quickly to a moderate maximum around 9,000 BP. Numerous other radiometric dates establish the peak of the Niger/Chad lake phase as 9,000 to 8,000 BP. Because Lake Chad depends to a large extent on rainfall from the humid Cameroon and Chad tropics, it is not an unambiguous indicator of subsaharan rainfall. However, such a tremendous increase of the Lake without the simultaneous increase in Sahelian rainfall is highly unlikely, and furthermore other lakes discussed clearly indicate that the presently semi-arid regions south of the Sahara were much wetter than today (Maley, 1977).

As in elsewhere, there are signs of an arid millenium about 7000 BP in Tibesti and Aïr mountains. At this period rivers began depositing large and badly sorted material characteristic of a drier climate, with a shorter and more pronounced rainy season, and stream flow from Tibesti into Lake Chad ceased about the same time, terminating construction of the Angamma terrace (Servant, 1973). In Chad, fresh water diatoms disappear and vertisol soils developed, indicating a tropical climate with contrasting seasons (Servant 1974). Following a brief arid episode towards 7000 BP in many of the tropical and subtropical regions discussed (Rognon and Williams, 1977; Nicholson, 1976; Street and Grove, 1976; Livingstone, 1979), a second lacustrine phase occurred from about 6500 to about 4500 BP, when a change began toward the present aridity. In Niger and Chad there was a return to wetter conditions at about 6500 BP. Similarly, in the Saharan highlands and other parts of central Sahara, and in much of north Africa, this humid lacustrine phase, c. 6500 to 4500 BP, is evidenced. The Niger formed a lake near Mopti and lakes in the Tenere and eastern Niger again reached high stands between then and about 4000 BP (Servant, 1973; Michel, 1973). Between 7000 and 6000 BP the surface of Lake Chad rose rapidly maintaining its high stand until c. 4000 BP. The Bama ridge a shoreline of Lake Chad (Mega Chad) has a 14C age of 6350 ± 250 yr. BP (Thiemeyer, 1993). This is evident that at around 6000 BP the Lake must have a high water level of about 320 m and a peak area of 340,000 Km2 (Figure4), further supporting the wetter conditions in the Lake Chad region during this period. Concurrently with this second humid period, Neolithic peoples spread into the driest regions of the Sahara (Gabriel, 1977).

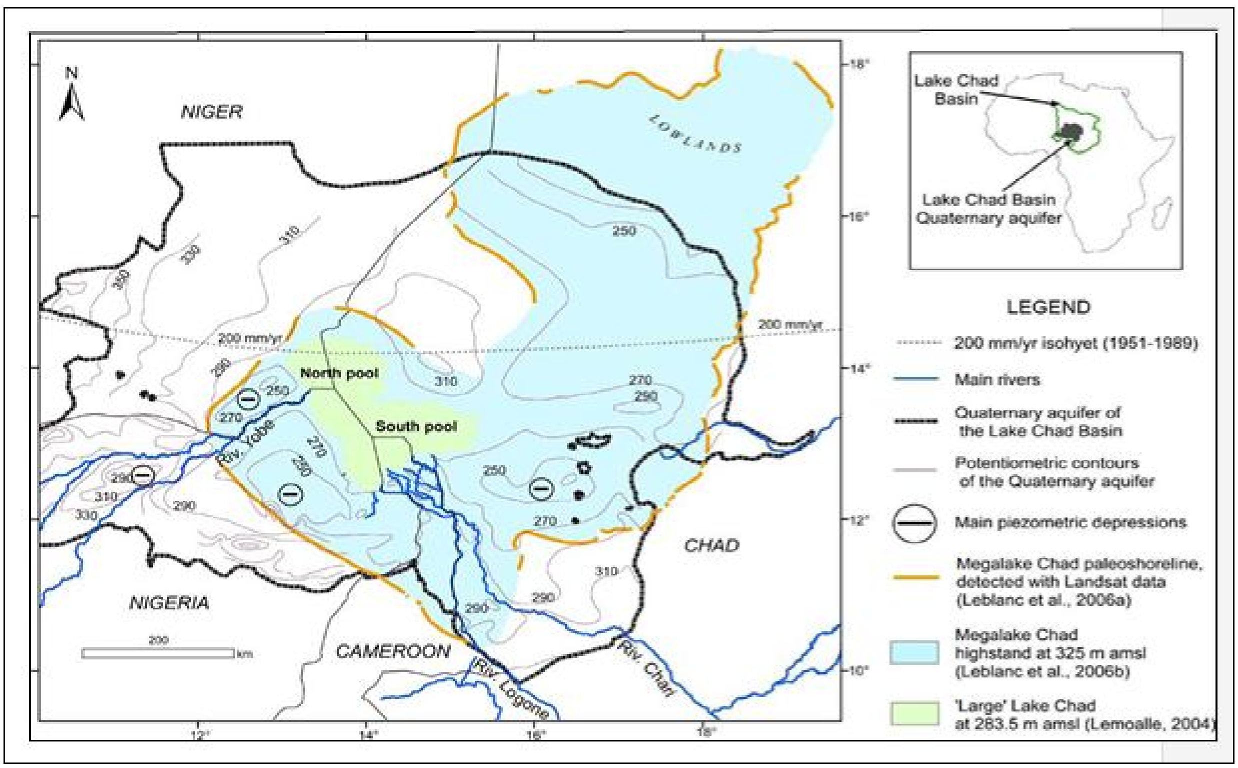

Figure 4: The Mega Lake Chad during the Holocene and its relationships with the unconfined Quaternary aquifer (Leblanc et al. 2007)

From 4 Ka to 2.5 Ka BP, a last positive hydrological phase occurred. Palustrine and lacustrine deposits in the entire Sahelian zone from the Atlantic coast to the Bahr El Ghazal testify to the higher water levels during this phase. Water table lowering, which preceded the modern hydrological conditions in the Sahel occurred not long before 1.8 Ka BP in Bahr El Ghazal, at Tjeri (Maley, 1981) and in the Kadzell area.

The past two millennia have been climatically relatively stable, as fluctuation within them have been small in comparison with those of the Pleistocene and early Holocene. There were, however, several episodes within the past two millennia in which the climate of various parts of Africa was significantly different from that of present. A transient wet phase centred on c. 1.6 ka BP, as indicated by the Sr/Ca ratios and d18O $_{ostracode}$ values, was accompanied by renewed dune activity in the Manga Grasslands, NE Nigeria, between 2.2 and 1.3 ka BP (Holmes et al., 1999). Both Sr/Ca ratios and d18O $_{ostracode}$ values indicate severe and prolonged drought between 1.2 and 1 ka PB in the Kajemarum Oases (Holmes et al., 1999). Ostracode and geochemical data indicate that Bal in the Manga Grasslands became a saline alkaline lake less than 0.5 ka BP, implying a dry climatic condition at that time.

2.3. Last Millenium

Changes in the levels of Lake Chad over the last thousand of years (Figure 5) have been used to demonstrate that climate of the region is also changing. This is because changes in the Lake level are controlled by climatic condition of the region. High lake level results from high discharge of rivers in the catchments to the lake, which is controlled by amount of rainfall in the catchment. In figure 6 it is clear that dry climate occurs in the mid 15th, 16th and 18th century. Wetter conditions occurred in the 14th and 17th centuries.

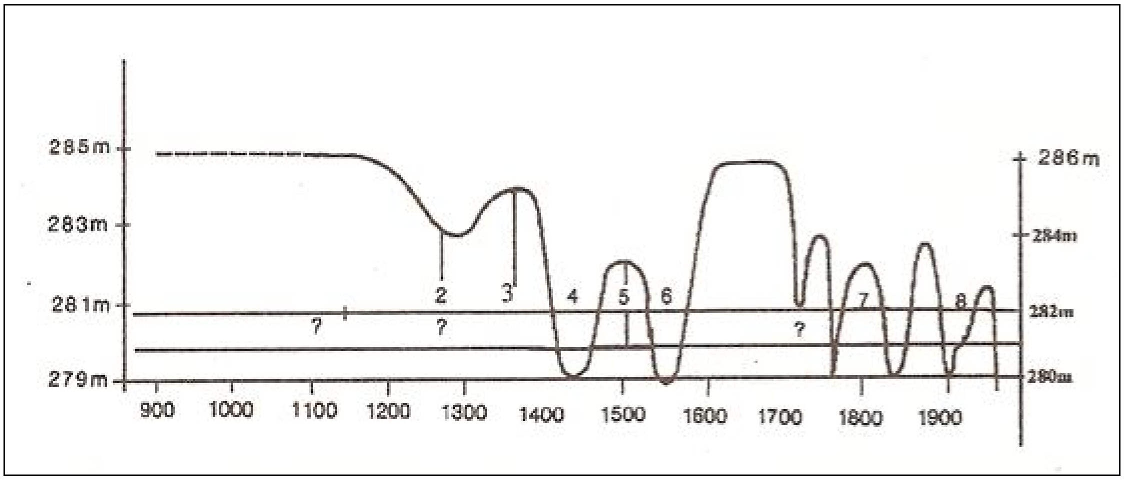

Figure 5: Reconstructed changes in Lake Chad level over the last millennium using both oral tradition and sediment analysis (Maley, 1981)

The Borno Chronicles (Lake Chad area) also gave descriptions of the reign of each king in some details from the 15th to the 18th century. Although dating of the reigns are an estimate based on works of historians (Nicholson, 1976), the chronicles are quite useful in deriving chronologies of famine and drought and 'prosperous' periods, providing information, which is in agreement with the rainfall changes suggested by the variation of Lake Chad (Maley, 1976). Lake Chad has been shown to be at high levels from the 16th to the 18th century, with a major fall in level around the 1630.

Urvoy (1949) describes all of the reigns of the 16th century at Borno as 'peaceful and prosperous', although occasional minor famines are mentioned under two rulers. The prosperous conditions lasted until the major famine of the 1680s, but conditions apparently improved for a time after this. There was an absence of famine until the mid-18th century and the reign of Hadj-Hamdun, for example, from c. 1726 to 1738, is described as one of peace, prosperity and even attention to learning and scholarship. From about 1790 conditions worsened and several famines occurred in the Borno area in the early to mid 19th century. Thus, one might conclude from the chronicles that the climate of Borno was more humid than today during the 16th century and most of the 17th century. They do not, of course, provide very conclusive evidence, but they do help to corroborate other types of information (Nicholson, 1980).

The hypothesis of wetter conditions in the Chad area several centuries ago, suggested by the variation of Lake Chad and information in the Borno chronicles, is further supported by historical and archeological evidence. This evidence include, the occupation of Tibesti from 1500 to 1700 and rapid depopulation towards 1700 (Plote, 1974). Maley (1973) also suggests a relation between climate and migration in the Tibesti area in the 17th and 18th century. The massif attracted nomads from drier areas such as the Fezzan and the Kufra areas, and peoples already occupying certain wetter valleys of the area were able to disperse into areas previously too arid for grazing. By the 19th century, a climate similar to present had been established, although a brief return to more humid conditions occurred in two or three decades of the late 19th century.

2.4. Last Century

The 20th century is the period of time where instrumental records exist in this part of the world. The Maiduguri meteorological station in the Nigerian sector of the Chad basin has records for most parts of this century (1915 – 2000). The rainfall records smoothed with a a 5 year moving average (Figure 6) show clearly the droughts of the 1940s and the 1980s. Carter and Barber (1958) have noted the rise in water table since 1932 supporting the wetter conditions of the 1930s, and also changes in land use (land clearing). However, annual fluctuations in the amount of rainfall are also discernible in instrumental records. Rainfall amount in the Nigerian sector of the Chad basin has declined in the periods since mid to late 1960s (Farmer and Wigley, 1985). The drought experienced in the 1970s and the 1980s has caused the mean annual rainfall for the Maiduguri station to decline from 657 mm for period 1915 – 1970 to 532 mm for the period 1971 – 1990, a reduction of approximately 20%. Rainfall has generally shown positive trend in the millennium (Figure 6). The mean annual rainfall at the Maiduguri station for the period 2001 – 2008 is 655 mm, very similar to the long-term average and thus some 20% higher than the average for the Sahel drought period. This decline in rainfall is the major cause of the present shrinkage of the Lake Chad from an area of 25,000 Km2 to about 3,000 Km2 over the past 50 years (Figure 7).

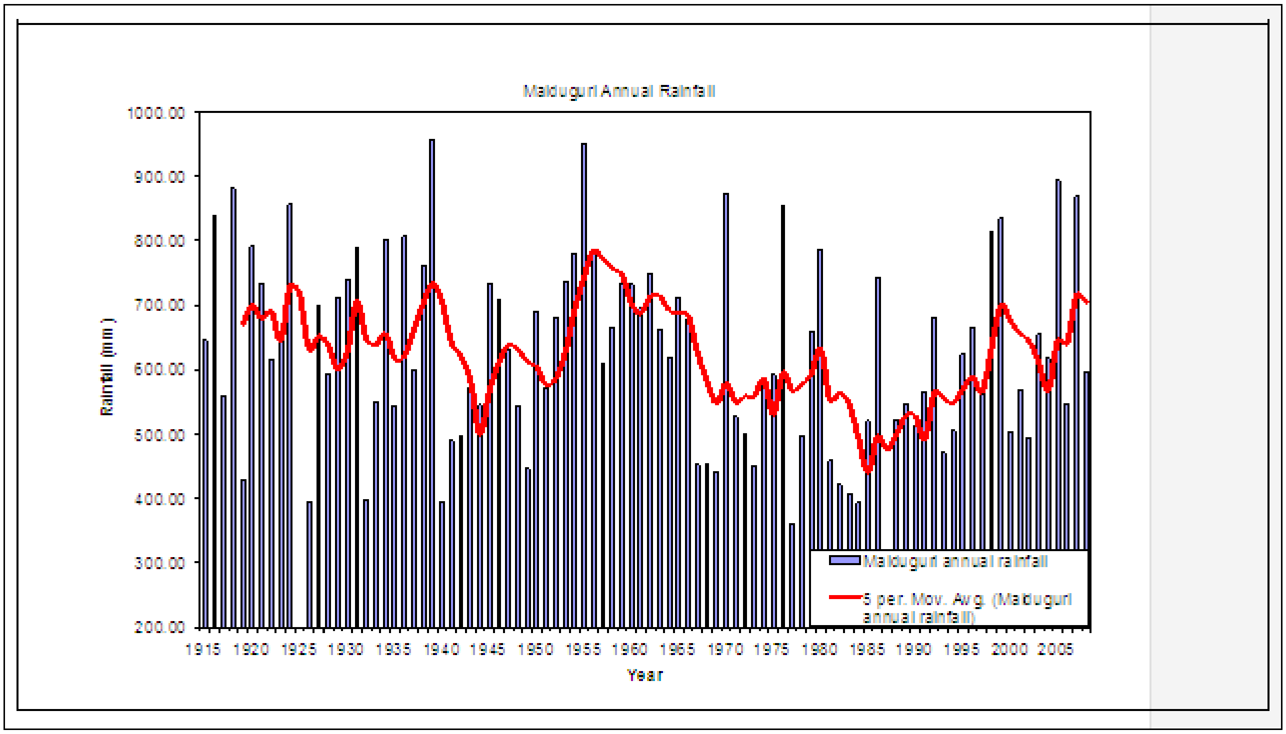

Figure 6: Records of annual rainfall for Maiduguri station and a 5-year moving average

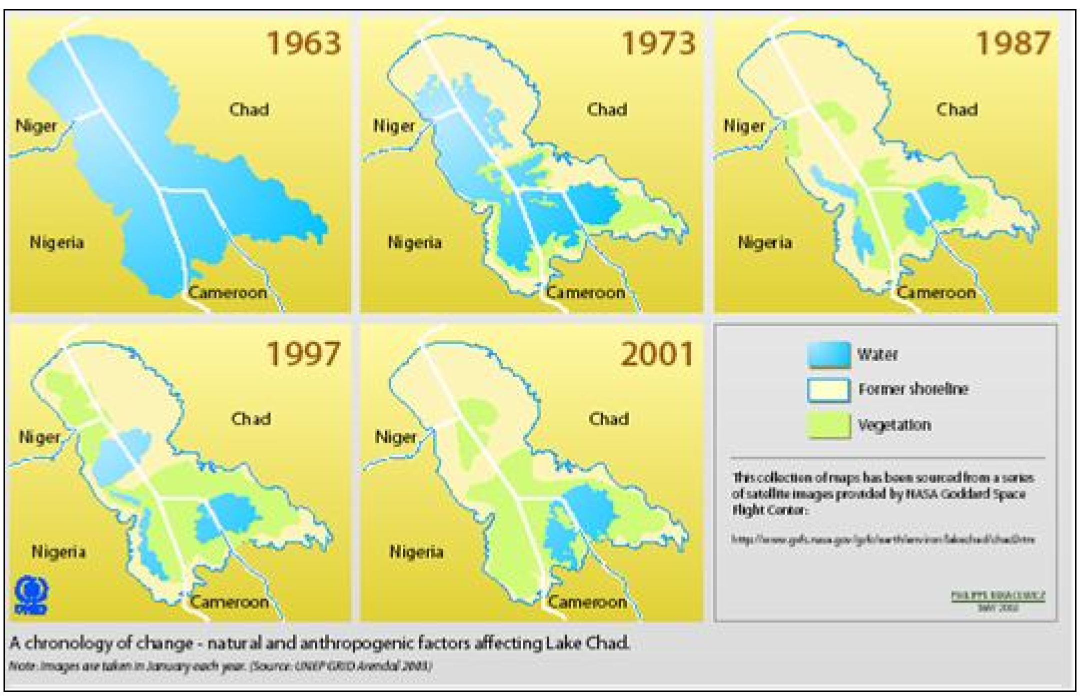

Figure 7: Changes in Lake Chad surface area over the 1963-2001 time period (UNEP, 2004).
The Lake shifted in the 1970s from a great lake (25,000 km2, 1960s) to a small lake (3000 – 7000 km2, 1980s-2000s)

Table 1 presents average annual river discharge to Lake Chad over long term and for the Sahel drought period. It clearly shows about fifty percent reduction in total discharge from all the rivers. Although, individually the rates of reductions varies from about forty percent for Chari, sixty percent for Kumadugu Yobe and eighty three percent for the ElBeid and others. This is a major contributor to the shrinkage of the Lake Chad over the last 50 years.

	River inflows in Km3/year			
Average over	Chari	Kumadugu Yobe	El-Beid and others	Total
Long term	37.8	1.0	1.2	40.0
1971-1990	21.8	0.4	0.2	22.4

Table 1: Changes in annual river discharge to Lake Chad (after Olivry et al., 1996)

In the Chad basin region, groundwater and surface water interact, which may be in the form of rivers or the Lake flowing to groundwater or vice versa. Here, there are indications of linkage between Upper aquifer of the Chad Formation and the Lake Chad water with flow from the Lake to groundwater (Figure 8). Thus, with increased abstraction, it is likely that groundwater level will decline and so create a gradient resulting in more water moving from the Lake to the groundwater in the Upper aquifer of the Chad Formation. This may also contribute to the shrinkage of the Lake, especially where an increase in population induces increased abstraction.

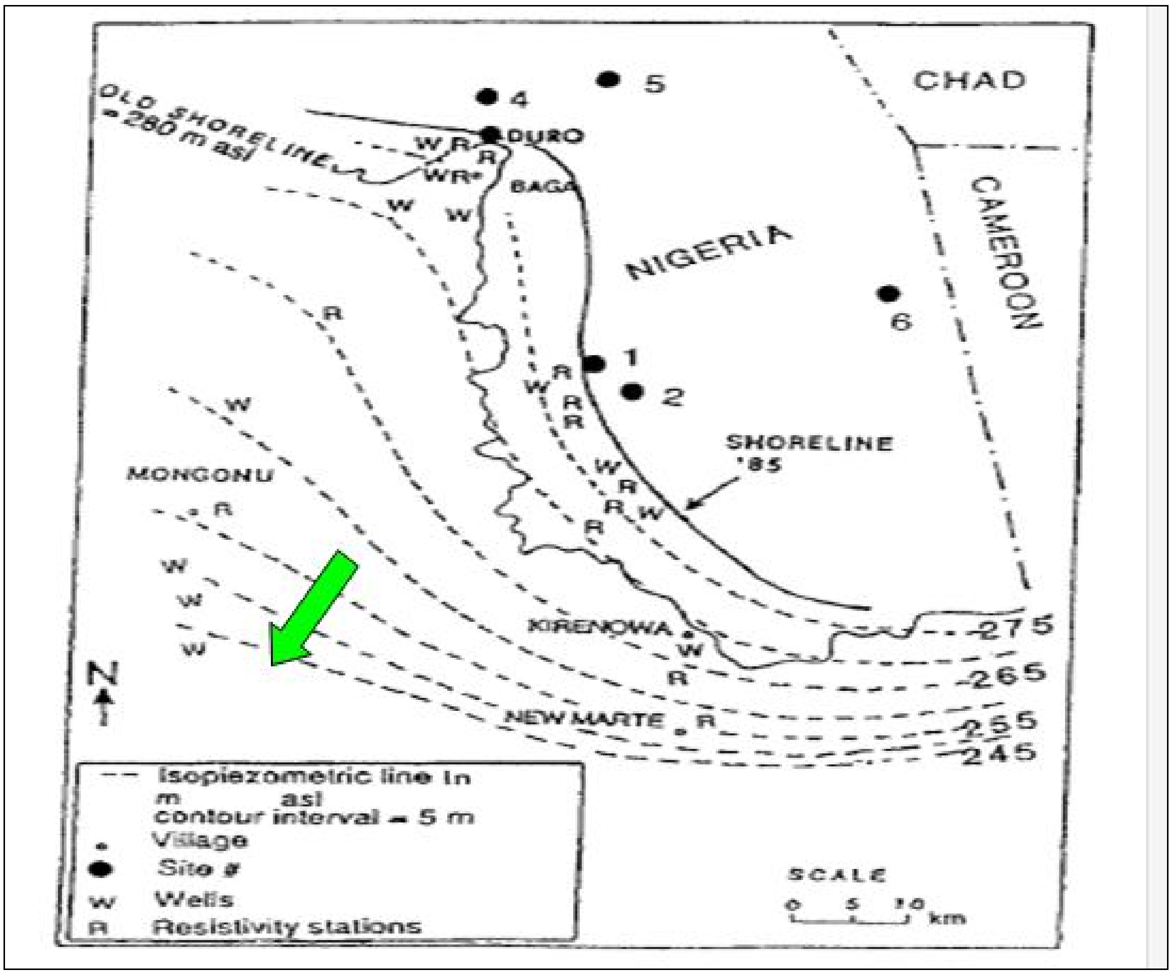

Figure 8: Hydraulic head of groundwater from Lake Chad shore showing flow moving southwest away from the Lake to the aquifer (Modified, after Isiorho and Matisoff, 1990)

3. Discussion

What is apparent from this review of the climatic conditions of the region is the evidence that several changes in climate and Lake Chad surface area have taken place from the late Pleistocene to the present day. These changes are largely as a result of natural climatic conditions, although in the recent times anthropogenic components are also apparent. In the natural realm, rainfall has been oscillating with consequent direct corresponding effect on the size and volume of water in the Lake Chad. This is discernible in figures 6 & 7. Siltation of river channels feeding the Lake Chad has also reduced flow to the Lake as water meant for the Lake over flows its banks easily resulting in flooding. The basin's present annual evapotranspiration is estimated at ~2000 mm (Olivry et al., 1996). This can be another contributor to changes in surface area of the Lake, albeit minimally.

On the anthropogenic factor, increased population in the basin and construction of dams are perhaps the most notable contributors to its recent shrinkage. Population has increased considerably over the last 50 years to about 37 million in the basin in 2003 (UNEP,2004). Population increase will likely result in increased demand for water and thus more stress to water resources of the basin including the Lake. This is happening at a time when the rainfall and Lake surface area have reduced considerably. Thus, the impact of the population growth is accentuated.

Discharge of Lake water to groundwater may also be a contributor to the shrinkage as Figure 8 has demonstrated that flow is from the Lake to groundwater. With continuous fall in water table due to increased demand and pumping as a result of population growth, hydraulic gradient should increase and thus more water flows from the Lake, increasing the shrinkage.

Construction of dams is a major threat to flow of water to the Lake Chad. The Tiga and Challawa dams were constructed in 1974 and 1992 respectively in Kano State Nigeria have caused about 45% reduction in the flow of Komadugu Yobe river, which drains to the northern pool of the Lake. Already, discharge to the Lake from catchment rivers has reduced by ~50% over the last 50 years (Table 1). A critical review will show that Chari river reduces by about 42%, Kumadugu Yobe by ~60% and El Beid by ~83%. Perhaps the cause of Chari's reduction is most explicable solely by dwindling rainfall compared to Komadugu Yobe and El-Beid, which have shown much greater percentage reductions. This may be due to additional anthropogenic factor of dam construction on the river course.

Given the fact that the population of the basin is about 85% rural and depended on animal and plant production as a means of survival, forced migrations became necessary as a result of changes in access to water. The people follow the water resources and settle on the territories of the south already made fragile by felling trees for firewood and trampling of plants by livestock. Fishermen follow the waters for several kilometres to fish. This increases competition and conflict amongst farmers, graziers and fishermen, raising tension in the region. The socio-economic problem is that these resources, which have become more limited and fragile, are also transboundary in nature (Jauro, 2007). Thus, graziers, fishermen and even farmers have been crossing the borders following changes in water resources accessibility.

To reverse and mitigate negative impacts of the shrinkage of the Lake Chad, inter basin water transfer is being canvassed as an option. The proposal (see, for instance, http://enc.tfode.com/Oubangui) is to bring water to the Lake Chad from the Congo basin, where 56% of African freshwater resources are being discharged into the Atlantic Ocean.

Although the shrinkage imposes lots of economic hardship, increased practice of recession agriculture emerged as an important source of supplement to the dwindling food resources in the region. Any transfer of water must take into account the impact to the communities. Resettlement in high grounds and their new found agricultural activity (recession farming) might suffice in the interim pending the revitalization of the Lake and its resources.

4. Conclusion

The climatic condition in the Chad basin has been oscillating from Pleistocene to the present times. These oscillations have resulted in corresponding effects on the Lake Chad surface area. Until recently, the oscillation of the Lake Chad is wholly climate controlled. However, in the recent times (over the last 50 years), anthropogenic factors have also been observed as possible contributors to the present shrinkage in the surface area of the Lake Chad. These factors are the damming of rivers discharging to the Lake, population growth and its attendant increase in water demands and agricultural practices that demand huge volumes of fresh water. The consequences of the present shrinkage are the increased competition over natural resources and its associated conflict amongst farmers, graziers and fishermen. This raises tension within and across nations as the resources are transboundary.

5. References

i. Carter, J.D. and Barber, W., 1958. The rise in the water table in parts of Potiskum division, Borno province. Records of Geological Survey of Nigeria 1956, Pp. 5-13.
ii. Coe, M.T and Foley, J.A., 2001. Human and natural impacts on the water resources of the Lake Chad basin. Journal of Geophysical Research, 106: 3349-3356.
iii. de Ploey, J., 1965. Position geomorphologique genese et chronologie due certains depots superficiels au Congo occidental. Quaternarla, 9, Pp. 131-154.
iv. Edmunds, W.M., Fellman, E. and Goni, I.B., 1999. Lakes, groundwater and palaeohydrology in the Sahel of NE Nigeria: evidence from hydrogeochemistry. J. Geol. Soc. London, 156, Pp. 345-355.
v. Farmer, G. and Wigley, T.W.L., 1985. Climatic trends for Tropical African. Research report to ODA UK. Climatic Research Unit, School of Environmental Sciences, University of East Anglia.
vi. Gabriel, B., 1977. Zum okologischen Wandel in der ostlichen Zentralsahara. Berl. Geogr. Abhandl., 27, 111p.
vii. Goni, I.B. (2006). Tracing stable isotope values from meteoric water top groundwater in the southwestern part of the Chad basin. Hydrogeology Journal 14(5), 742-752.
viii. Grove, A.T., 1996. Africa river discharges and lake levels in the twentieth century. In: Johnson, T.C. and Odada, E. (eds.). Liminology, Climatology and Palaeiclimatology of the East African lakes. Gordon and Breach, Newark, N.J. pp 95-100.
ix. Holmes JA, Street-Perrott FA. Perrott RA, Stokes S, Waller, MP, Huang Y, Eglinton G, Ivanovich, M., 1999. Holocene landscape evolution of the Manga Grasslans, Northern Nigeria: evidence from palaeolimnology and dune chronology. J. Geol. Soc. London, 156, Pp. 357-368.
x. Isiorho, S.A. and Matisoff, G., 1990. Groundwater recharge from Lake Chad. Limnology Oceanography, 35, pp. 931-938.

xi. Jauro, A.B., 2007. Socio-economic issues and conflict resolution in water resources use. A paper presented at a Regional Roundtable on Sustainable Development of the Lake Chad Basin, organized by DTCA at the University of Maiduguri.
xii. Leblanc, M., Favreau, G., Tweed, S., Leduc, C., Razack, M. & Mofor, L. (2007) Remote sensing for groundwater modelling in large semiarid areas: Lake Chad Basin, Africa. Hydrogeology Journal 15(1), 97-100.
xiii. Livingstone, D.A., 1979. Environmental changes in the Nile headwaters. In: M.A.J. Williams and H. Faure (eds.), The Sahara and the Nile. A.A. Balkema, Rotterdam.
xiv. Maley, J., 1976. Les variations du lac Tchad depuis un millenire. Consequences paleoclimatiques. Palaeoecology of Africa, 9, Pp. 44-47.
xv. Maley, J., 1977. Palaeoclimates of central Sahara during the early Holocene. Nature, 269, Pp. 573-577.
xvi. Maley, J., 1981. Etude Palynologigues dans le Bassin du Tchad et Paleoclimatologie de l'Afrique nord-tropicale de 30,000 ans a l'Epoque actuelle. Travaux et Documents de lORSTOM, 129, 586p.
xvii. Mathewson, A.P., Shimmield, G.B., Kroon, D. and Fallick, A.E., 1995. A 300 kyr high-resolution aridity record of the north African continent. Palaeoceanography, 10 (3), Pp. 677-692.
xviii. Michel, P., 1973. Les bassins des fleuves Senegal et Gambie, etude geomorphologique, 2 ORSTOM, Mem. 63, Paris.
xix. Nicholson, S.E., 1976. A Climatic Chronology for Africa. Synthesis of Geological, Historical and Meteorological Information and Data. Ph.D. Thesis, University of Wisconsin, Department of Meteorology, 324p.
xx. Nicholson, S.E., 1980. Saharan climates in historic times. In: Williams, M.A.J. and Faure, H. (eds.), The Sahara and the Nile. Rotterdam. Pp. 173-200.
xxi. Nicholson, S.E., 1996. A review of climate dynamics and climate variability in eastern Africa. In: Johnson, T.C. and Odada, E. (eds.), The Liminology, Climatology and Palaeoclimatology of the East African Lakes. Gordon and Breach, Pp. 25-56.
xxii. Nicholson, S.E., 2000. The nature of rainfall variability over Africa on time scales of decades to millenia. Global and Planetary Change, 26, Pp. 137-158.
xxiii. Olivry, J. C., Chouret, A., Vuillaume, G., Lemoalle, J. & Bricquet, J. P. (1996) Hydrologie du Lac Tchad. Monographie hydrologique n° 12, ORSTOM edn., Paris, France.
xxiv. Oteze, G.E. and Fayose, S.A., 1988. Regional development in the Hydrogeology of Chad basin. Water resources, 1(1), Pp. 9-29.
xxv. Plote, H., 1974. L'Afrique sahelienne se desseche-t-elle? Bur. Rech. geol. et minieres, Service geologique national, Orleans, France.
xxvi. Rognon, P. and Williams, M.A.J., 1977. Late Quaternary Climatic Changes in Australia and north Africa: A Preliminary Interpretation. Palaeogeogr. Palaeoclimatol. Palaeoecol., 21, Pp. 285-327.
xxvii. Servant, M., 1973. Sequences continentales et variations climatiques: evolution du bassin du Tchad au Cenozoique superieur. Ph.d. Thesis, University of Paris, 348p.
xxviii. Servant, M., 1974. Les variations climatiques des regions intertropicals du continent African depuits la fin du Pleistocene, XIII Journees Hydr., Paris, 11p.
xxix. Stokes, S. and Horrocks, J., 1998. A reconnaissance survey of the linear dunes and loess plains of northwestern Nigeria. In: Alsharhan AS, Glennie KW, Whittle GL, Kendall CGStC. Quaternary Deserts and Climatic Change. Balkema, Rotterdam pp 175-184.
xxx. Street, F.A. and Grove, A.T., 1976. Environmental and climatic implications of Late Quaternary lake-level fluctuations in Africa. Nature, 261, Pp. 385-390.
xxxi. Thiemeyer, H., 1993. A new 14C record from the Bama ridge near Konduga, Borno State, NE Nigeria. Annals of Borno, 8/9, Pp. 239-242.
xxxii. UNEP (2004). Fortnam, M.P., Oguntola, J.A. (Eds.), Lake Chad Basin, GIWA Regional Assessment 43, University of Kalmar, Sweden, 129 p. Aslo available at: http://www.giwa.net/areas/reports/r43/giwa_regional_assessment_43.pdf
xxxiii. Urvoy, Y., 1949. Histoire de l'empire du Borno, mem. Inst. fr. Afr. noire 7, Dakar.