NATURAL RESOURCES DEPLETION, POLLUTION AND RESTORATION OF LAKE CHAD

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Abstract

Lake Chad, one of the largest lakes in Africa with an estimated surface area of 2,434,700km^2 covers about 8% of the continent and a geographical basin cutting across Western and Central Africa. The lake is surrounded by various ecological zones such as deserts, forests, wetlands, savannas, mountains and rich diversity of flora and fauna, some of which are peculiar to the region. The lake provides water supply, groundwater recharge, fishery, support livestock, water-based transportation, wood and forest products, irrigation, mining, and oil exploration. Over the years, the lake has drastically reduced in size due to several anthropogenic factors such as climate change, over-exploitation of natural resources and population growth which have acted synergistically to affect the lake resulting in shrinking to about 10% of its original size. These activities have led toa significant decline in biodiversity and pollution of surface and groundwater, sediments and soil. The ambitious plan for restoring Lake Chad will be practically impossible without a comprehensive institutional and regulatory reform, environmental assessment, and effective remediation and restoration efforts. As the population depending on the basin is projected to reach about 66 million people by 2025, there is a need for robust management of the natural resources of the basin for sustainable development of the region.

Keywords: Lake Chad; climate change; resource degradation; pollution studies; ecological restoration

1.0 INTRODUCTION

Lake Chad is one of the largest lakes in Africa with an estimated surface area of 2,434,700 km^2, covering about 8% of the continent and a geographical basin cutting across Western and Central Africa (Fortnam and Oguntola, 2004; GIZ, 2015a; LCBC, 2015). It is the third-largest endorheic lake in the world, after the Caspian and Aral Seas (Ramsar 2001a). The active basin is under the authority of the Lake Chad Basin Commission (LCBC, 2015). Historically, before 5000 BC, Lake Chad was reported to be the remnant of an ancient inland sea, which covers an area of about 1,000,000 km^2. The lake formerly known as Mega chad connects the Niger River into the Atlantic Ocean (Drake and Bristow, 2006; Leblanc *et al.*, 2006). Chad as a country derived its name from the lake which means 'a large expense of water' (Room, 1994). Over the years, the lake has drastically reduced in size due to several anthropogenic factors prevailing on the lake over the last two centuries. The lake is now about 10% of its original size (Okpara *et al.*,2015; LCBC, 2015; GIZ, 2015a). Rainfall within Lake Chad axis varies significantly and usually ranges from 1,400 mm/year in the southern axis to 10 mm/year in the northern region (Bontemps, 2013). Rainfall occurs between June and August and sometimes October. The area is characterized by high temperature and intense solar radiation with very low humidity and strong wind leading to a high annual potential evapotranspiration around the lake (Carmouze, 1976). The temperature of the lake is projected to increase by 0.65 - 1.6 °C and precipitation to decrease by 13 - 11% within the next two decades (Mahmood *et al.*, 2019). The lake is characterized by four climatic zones

(Figure 1). They include the humid zone in the southern basin, which is bounded by Cameroon and the Central African Republic (CAR); the sub-humid zone which is bounded by CAR and Chad; the semi-arid zone at the central basin of the lake, and bounded by Chad, Nigeria and Niger and the main arid zone in the northern basin which is bounded by Niger and Chad (Bontemps, 2013).

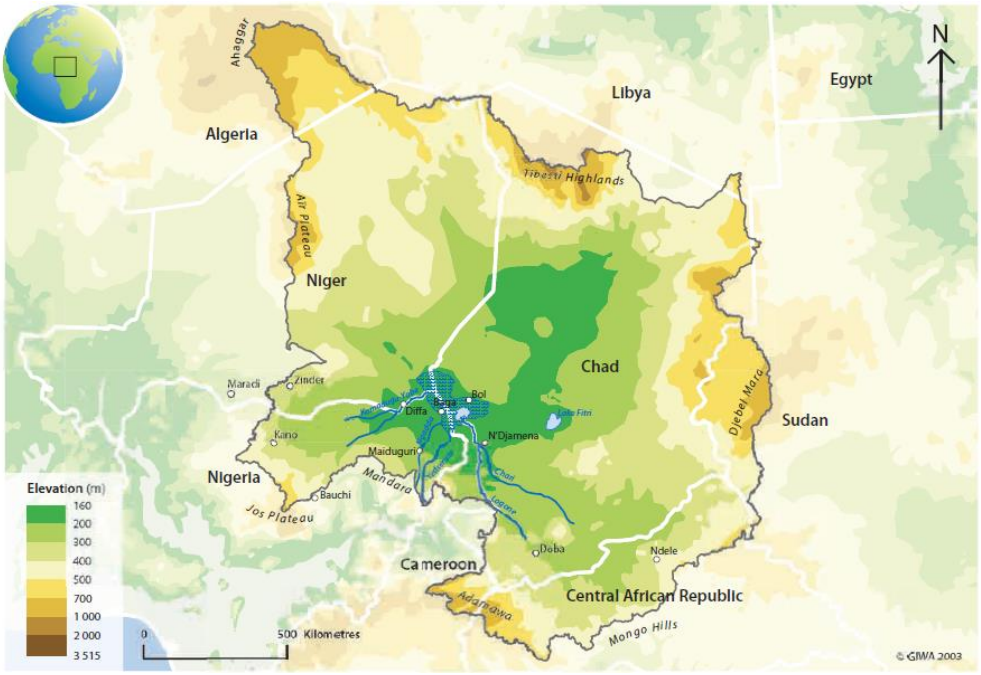

Figure 1: Lake Chad basin (Fortnam and Oguntola, 2004)

The lake is largely supplied hydrologically by three main drainage systems (Okpara *et al.*, 2015). The Chari River with its headwaters in CAR flows through Chad Republic following the Cameroon boundaries into Lake Chad. It is joined by the Logone River, which is the main tributary of the Chari River before reaching the lake. The Chari-Logone River provides over 90% of the water reaching the lake (Okpara *et al.*, 2015). The two other drainage system such as the Komadugu-Yobe River in Nigeria and the Yedsaram/Ngadda River in Cameroon supplies less than 10% of the lake water and aquatic resources (Okpara *et al.*, 2015). The lake is surrounded by unique varieties of ecological zones such as deserts, forests, wetlands, savannas and mountains consisting of a wide range of flora and fauna (Ovie and Emma, 2011). Within the basin, there are very important and well-known swamp regions: the Yaérés in the extreme north of Cameroon, Lake Fitri, the Massénya and the Salamat to the south and southeast of the Lake Chad, respectively. Lake Chad is a large shallow lake with an average depth of 1.5 metres and a maximum depth of 10.5 metres at the deepest part of the lake. Due to its shallowness, most of the lake area in the southern and northern pond can be considered as a swamp (Vassolo, 2012). The lake has been stratified into four development circles such as Large Lake Chad, Normal Lake Chad, Small Lake Chad, and Dry Small Lake Chad. This description is largely based on water quantity and geographical coverage over the last century (GIZ, 2015b).

Buoyed by the dwindling lake and the need to create a body for the management of the lake, a regional or intergovernmental organization known as the Lake Chad Basin Commission

(LCBC) was established on May 22, 1964, by four countries (Cameroon, Chad, Niger, and Nigeria) where the active basin resides with headquarters in the capital of Chad, N'Djamena. Considering the geographical basin of the lake which extends beyond these four countries, other countries such as the Central African Republic, Libya, Algeria, and Sudan were later admitted into the LCBC. Subsequently, Egypt, Congo, and the Democratic Republic of Congo (Figure 2 and 3) were admitted as observers (LCBC, 2015). The mandate of LCBC was the management of water and other natural resources of the basin and coordinates programmes and projects for the effective management of the resources of the basin. Based on the founding convention, funding for the commission is provided by member countries through an agreed quota with the Central African Republic providing 4%, Niger 7%, Chad 11%, Cameroon 26%, and Nigeria 52% (LCBC, 2015).

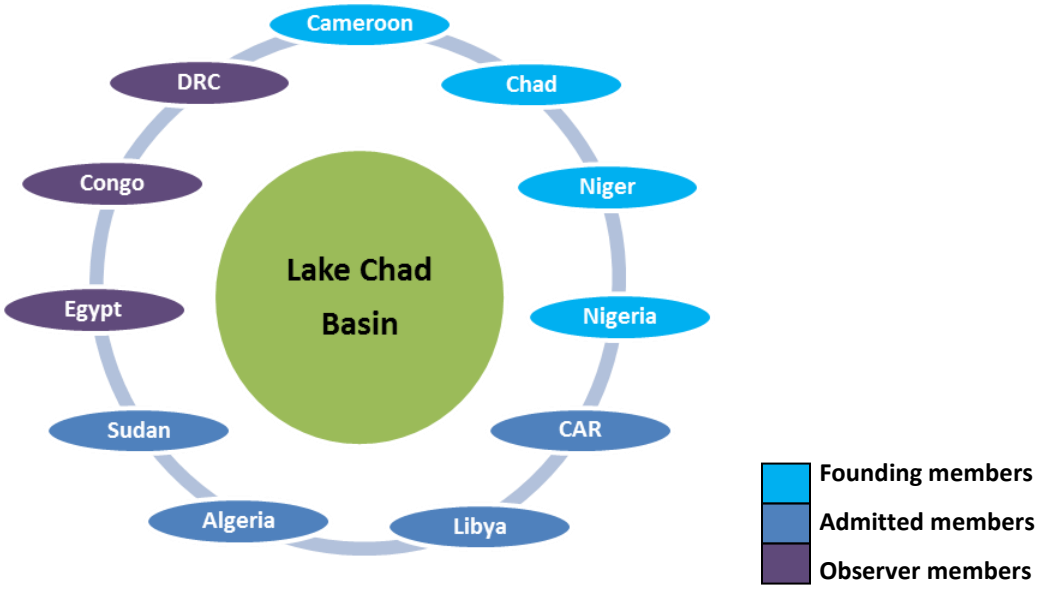

Figure 2: Membership of Lake Chad Basin Commission

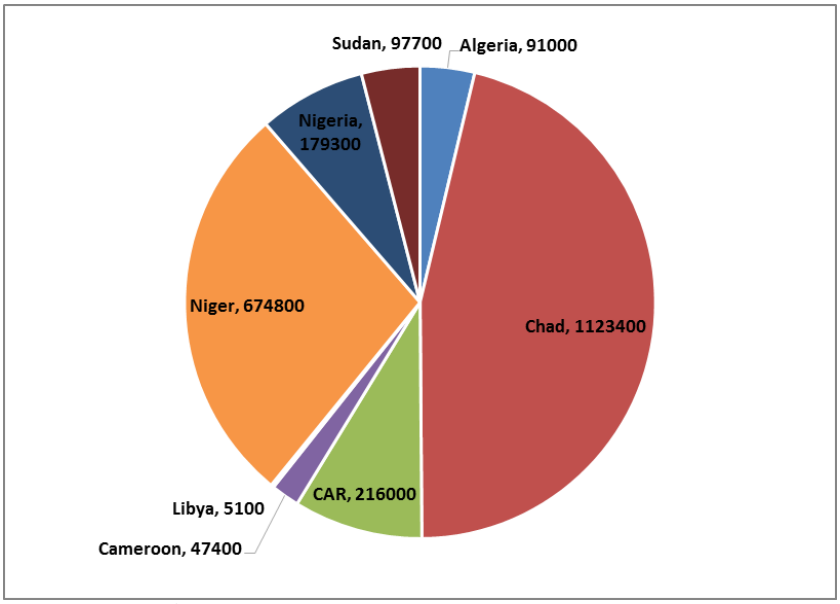

Figure 3: Coverage area (km^2) of Lake Chad basin by country (Fortnam and Oguntola, 2004)

2.0 Natural Resources of Lake Chad Basin

Lake Chad is a fragile ecosystem that is rich in natural resources. It is a major wetland in the African Sahel belt (Aminu-Kano, 2002) and provides crucial economic and ecological life support services to the West and Central African region.

2.1 Ecological Resources of Lake Chad

Although no comprehensive survey of the biological resources of the lake is available, efforts have been made at different times to document aspects of the biological resources of the basin. The lake provides water supply, groundwater recharge and abundant diversity of flora and fauna, some of which are peculiar to the region. The lake is reported to have diverse species of flora adapting to the various micro-ecological zones found within the basin. The lake is reputed as one of the largest producers of spirulina worldwide, with over 44 species of algae and a diversity of plant species (Beadle, 1981; Denny, 1991; Mockrin and Thieme, 2009; LCBC, 2015).

Vegetation around Lake Chad includes forest, trees, shrubs, herbs, woodlands, and grasslands. Species of trees found in the basin include baobabs, arid date palms, African myrrh, and Indian jujube (Mockrin and Thieme, 2009). Herbaceous trees and grasses include *Caperonia palustris*, *Echinochloa colona*, *Hibiscus asper*, *Hygrophila auriculata*, *Sorghum purpureosericeum* and *Schoenfeldia gracilis* (White, 1983). The indiscriminate exploitation of wood for energy and furniture has resulted in the decline and disappearance of certain species of trees within the lake region (Jimoh, 1989; Raji and Omoyeni, 2005). Invasive plant species, especially aquatic macrophytes are now the dominant vegetation covering about half of the water surface (GIZ, 2015b). Invasive species such as cattails, water hyacinth, vetiver grass, are largely associated with water resources undergoing some level of degradation. Such invasive plant out-competes local species facing stress because of increasing contamination in the lake. Aquatic vegetation or macrophytes found in the wetlands include reeds, water hyacinth (*Eichhornia crassipes*), vetiver grass (*Vertiveria nigritana*), *Hyparrhenia rufa*, *Oryza longistaminata*, *Echinochloa pyramidalis*. Others include *Cyperus papyrus*, *Phragmites mauritianus*, *Phragmites australis*, *Vossia cuspidata*, *Typha australis*, *Pistia stratiotes*, and *Acacia seyal* (gum Arabic), some of which grows in the saline waters in the northern basin (Beadle 1981; Denny 1991; Mockrin and Thieme, 2009; LCBC, 2015).

The various ecological zones in the basin hold a rich diversity of fauna. About 179 species of fishes are reported in the lake, which are prevalent in other basins such as the Niger, Nile and CongoRiver basins as evidence from the Pleistocene suggests (Hughes and Hughes, 1992). Only 25 endemic species have been described in the lake (Hughes and Hughes, 1992) dominated by pelagic fishes, including the Kouri ox which is threatened (Ramsar, 2001; LCBC, 2015). Some species of commercial fishes found include *Alestes baremoze*, *Polypterus ansorgii*, *Clarias anguillaris*, *Oreochromis niloticus*, *Synodontis nigrita*, *Bagrus docmac* and *Lates niloticus* (Gwaski *et al.*, 2013a; Keith and Plowes 1997; Mockrin and Thieme, 2009). The population of characin (*Alestes baremoze*) and Nile perch (*Lates niloticus*) have decreased drastically (Keith and Plowes 1997; Mockrin and Thieme, 2009). Fish stock in the lake is now dominated by tilapia and catfish, two fish species that are known to survive in aquatic ecosystems with low levels of oxygen (LCBC, 2015).

Several species of migrating birds are reported in the lake (LCBC 2015). The lake provides refuge for Palearctic and Afrotropical birds (Mockrin and Thieme, 2009). The lake acts as a migratory route for resting, wintering, or breeding for diverse species of birds. About 1 million Palearctic birds spend winter on the lake (Mockrin and Thieme, 2009). Migratory birds found in

the lake include wintering ducks, ruff, waterfowl, and shorebirds. The wader ruff (*Philomachus pugnax*) is reported as the most abundant in the lake with a population of over a million in the late nineties (Keith and Plowes 1997; Mockrin and Thieme, 2009). Other species of birds include garganey (*Anas querquedula*), northern pintail (*Anas acuta*) white-faced whistling duck (*Dendrocygna viduata*), (Garba-Boyi *et al.*, 1993; Scott and Rose 1996; Dodman *et al.*, 1999), marabou stork (*Leptoptilos crumenifer*),gull-billed tern (*Gelochelidon nilotica*), reed cormorant (*Microcarbo africanus*), (Ramsar, 2001b) and the marbled teal (*Marmaronetta angustirostris*) which is rapidly declining worldwide (Mockrin and Thieme, 2009).Two endemic birds in the region include the river prinia (*Prinia fluviatilis*) and rusty lark (*Mirafra rufa*). The lake is a nesting site for the vulnerable black-crowned crane (*Balearica pavonina*), (Mockrin and Thieme, 2009). There were growing concerns about the unavailability of nesting sites for the endangered West African black-crowned crane (*Balearica pavonina*) and lack of wintering grounds for migrating ruff (*Philomachus pugnax*), (Mockrin and Thieme, 2009).

Mammals present in the lake before the drastic decline includered-fronted gazelle (*Gazella rufifrons*), dama gazelle (*Gazella dama*), dorcas gazelle (*Gazella dorcas*), patas monkey (*Erythrocebus patas*), cheetah (*Acinonyx jubatus*), striped hyena (*Hyaena hyaena*), caracal (*Felis caracal*), and the endangered wild dog (*Lycaon pictus*) (Happold 1987; Mockrin and Thieme, 2009). Others include African elephant (*Loxodonta africana*), otters (*Lutra maculicollis, Aonyx capensis*), hippopotamus (*Hippopotamus amphibius*), sitatunga (*Tragelaphus spekei*), kob (*Kobus kob*), crocodiles, antelopes, addax, and black rhinoceros (Mockrin and Thieme, 2009; Bontemps, 2013). Populations of these species were probably quite widespread when the lake was more extensive. Two species of endemic rodents such as *Mastomys verheyeni* and the Lake Chad gerbil, *Taterillus lacustris* have been reported as well (Mockrin and Thieme, 2009). Most of the wild animals, especially mammals have disappeared due to declining habitat and over-exploitation from the growing human population around the basin (Mockrin and Thieme, 2009). The sitatunga (*Tragelaphus spekei*) has reportedly gone extinct in Niger (Mockrin and Thieme, 2009). The population of several species, including hippos and Nile crocodiles have critically declined (Hughes and Hughes 1992; Mockrin and Thieme, 2009).

The rich biological diversity present in the Chad basin led to the declaration and recognition of the lake as a Transboundary Ramsar Site of International Importance by the Lake Chad Basin Commission in collaboration with the Ramsar Convention on 28th July 2000. The lake was further designated as a World Natural Heritage Site by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2012, (LCBC 2015).

2.2 Economic Resources of Lake Chad Basin

Lake Chad is strategic to the economic activities and population within the basin. The lake provides water, fishery, supports livestock industry, water-based transportation, wood and forest products and irrigated agriculture to about 2 million people at the bank of the lake (Raji and Omoyeni, 2005; LCBC 2015) and about 13 million people in two major cities such as Maiduguri in Borno State, Nigeria and N'Djamena, the capital of Chad (LCBC, 2015). The entire activity around the Lake Chad axis supports about 47 million people (LCBC 2015). The economic activities within the basin include subsistence and cash crop farming, fishing, artisanal mining, oil exploration and small scale manufacturing and food processing (Fortnam and Oguntola, 2004).

Agriculture is the major occupation in the basin with a cultivated area (Figure 4) covering about 2,800,000 hectares across Niger (2,010,000), Nigeria (560,000), Chad (125,000) and Cameroon (44,500), (GIZ, 2015a). The drying up of the lake has extended the cultivated areas,

presently estimated to cover about 7,000,000 hectares (GIZ, 2015a; LCBC, 2015). The agricultural practices include rain-fed, flood receded and irrigated agriculture (Table 1) with the latter playing a dominant role for the last 50 years (GIZ, 2015b).Cash crops grown in the basin include peanuts, cassava, maize, wheat, millet, sorghum, rice, cotton, potato, melon, tomato, capsicum, garlic, and onion. Chad and Cameroon basin of the lake was estimated to produce about 600,000 to 900,000 tonnes of maize annually before the severe drought (GIZ, 2015a). Sorghum production and yield decline from about 250,000 tonnes produced in the seventies to 180,000 tonnes in the eighties (Fortnam and Oguntola, 2004; Okpara *et al.*, 2015) which has further declined in recent years (USGS, 2014). Animal husbandry includes livestock farming such as cattle, camels, horses, sheep, goats, and donkeys (GIZ, 2015a). About 250,000 cattle were sold in 2014 along the basin towards Maiduguri (LCBC 2015).

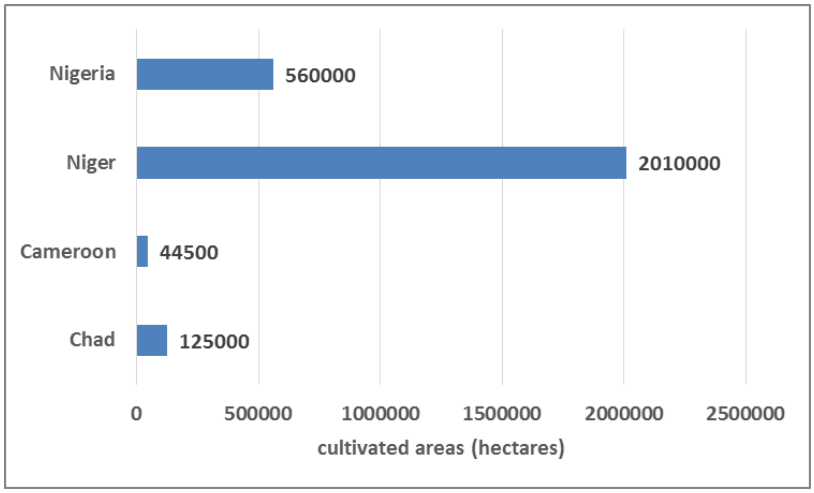

Figure 4: Cultivated areas of Lake Chad (GIZ, 2015a)

Fishery production within the basin increased significantly within 1967 and 1972 (Durand, 1973). The shrinking lake resulted in the collapse of the fishery sector in the northern and southern axis of the lake by 1982 (Fortnam and Oguntola, 2004). The receding lake led to the drastic fall in annual fish production from over 200,000 tonnes in the 1970s to about 20,000 tonnes in 1987 (Neiland and Verinumbe, 1990; Fortnam and Oguntola, 2004). Prior to the severe drought experienced by the lake, Chad and Cameroon basin of the lake was estimated to produce about 60,000 to 80,000 tonnes of fresh fish annually (GIZ, 2015b). As the lake decline and resources are impacted, production in fishery resources also declines. Only about 50,000 to 100,000 tonnes of fishery resources were produced in 2010 (LCBC, 2015). As the fishery resources decline, most fishers tend to move into other agricultural farming methods for survival (LCBC, 2015).

Table 1. Occupation and sources of income around Lake Chad basin (Fortnam and Oguntola, 2004)

Activity	**Amount (million USD)**
Animal husbandry	14.7
Fishing	45.1
Large irrigated areas	9.4
Rain-fed and flood recessional cropping	26.6
Small irrigated areas	10.8

Although mining activity is limited, the Lake Chad basin is very rich in mineral resources. Mineral resources contained within the basin include kaolin, natron or soda ash (potash), gravel, diamond, gold and petroleum (Fortnam and Oguntola, 2004). Gold and diamonds are essentially mined in the Tandjile and Mayo-Kebbi regions of Chad which borders CAR (Fortnam and Oguntola, 2004). Artisanal mining for natural resources, especially potash is a source of income for households in the region (Raji and Omoyeni, 2005) while active water transportation in the lake region is evolving rapidly. Potash is excavated and use as salt for the production of herbal medicines and soaps (Fortnam and Oguntola, 2004). The discovery of oil within the Lake Chad basin led to the exploration for oil due to its global economic value and as a major source of income for African nations. There is an active oil exploration in the Lake Chad basin and the construction of a trans-Atlantic oil pipeline in the north. There are also oil and gas exploration activities springing up in Cameroon, Chad, Niger, and Nigeria axis of the lake as a vital economic resource for the respective member states of the basin (Mockrin and Thieme, 2009; LCBC, 2015).

It is projected that a population of about 66 million people will depend on the lake by 2025 and a staggering population of 129 million in 2050 (LCBC, 2015). This implies that Lake Chad will face more pressure as we move into the future. There is a need for effective management of the natural resources of the basin for sustainable development of the region.

3.0 Natural Resources Degradation and Pollution of Lake Chad

Lake Chad underwent tremendous environmental degradation within the last two millennia. From the disappearance of Megachad to the decline and resource degradation within the last fifty years, the lake has undergone critical shrinking threatening biological resources and economic activities of the population in the region. Water, soil, biodiversity, and economic resources are undergoing some form of degradation within the basin (Figure 5).

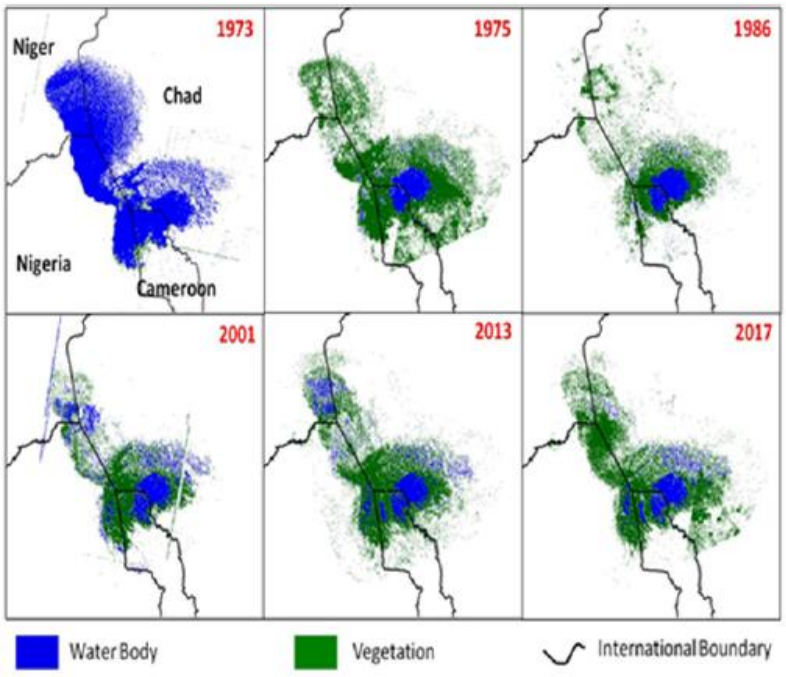

Figure 5. Declining Lake Chad between 1973 to 2017 (Nagabhatla and Brahmbhatt, 2020)

3.1 Sources of Natural Resources Depletion in Lake Chad Basin

There are different arguments and opinions about the factors leading to the drastic decline and degradation of the Lake Chad basin, but the generally accepted scientific consensus include (LCBC, 2015; GIZ, 2015a);

a) **Climate Change** - unprecedented change in the atmosphere and climatic condition largely as a result of anthropogenic activities
b) Over-Exploitation of natural resources such as the construction of hydroelectric dams, irrigation for agriculture, obnoxious fishing practices, indiscriminate use of agrochemicals, uncontrolled collection of wood products, etc.
c) **Population growth** - Lake Chad is situated in Western and Central Africa, an area with one of the highest population growth in the world.

3.2 Resources Degradation and Environmental Pollution

There is a tremendous degradation of the natural resources of Lake Chad but there is a paucity of baseline information or data to quantify the extent of degradation of the Lake Chad basin. There are limited documented evidence pointing to the growing degradation and pollution of natural resources, including water, soil, flora and fauna in the region. There are also reports of impending degradation and pollution along the tributaries of the active basin in member states.

These major factors have acted synergistically to affect Lake Chad resulting in the current dismal condition of the lake. The Sahel region is exposed to high warming weather pattern with intense temperature and heat almost all through the year (Carmouze, 1976). The expansion in the production of cash crops leads to astronomical increased in irrigation projects in the late eighties, which impacted the lake beyond its sustainable limit (UNDP, 2006; Vassolo, 2012). There are extensive presence and usage of pesticides (Akan *et al.*, 2013). There is pollution from textiles and tannery effluents from municipal and industrial activities at the upstream axis of the basin (Akan *et al.*, 2013). Untreated wastewater discharges from communities along the Chari-Logone and Komadugu-Yobe River pathways, especially from agrochemicals, slaughterhouses, hotels, and hospitals also contribute to pollution of the lake (Akan *et al.*, 2013). Artisanal mining for potash is also a source of pollution in the basin. The oil industry activity in the Lake Chad basin is a potential source of pollution, especially the acquisition of seismic data and drilling of exploration wells.

Lake Chad has experienced a rapid decline in biodiversity as a result of significant pressure from anthropogenic activities. Over-exploitation and receding habitat led to the decline and in some cases the complete disappearance of animals like hippopotamuses, crocodiles, elephants, gazelles, antelopes, hyenas, cheetahs, caracals, addax, black rhinos in the basin (Mockrin and Thieme, 2009; LCBC, 2015; GIZ, 2015b). The population of the Kuri cattle breed, an endemic species, present in the Lake Chad basin, is threatened with extinction due to dwindling vegetation cover in the region over time (GIZ, 2015b). Livestock is one of the most vital economic products of poor people around the lake. Livestock includes cattle, sheep, goat, camel, horses, and donkey. There is indiscriminate and extensive grazing of vegetation by the livestock population within the basin, thereby resulting in the destruction and disappearance of vegetation cover (Raji and Omoyeni, 2005).

There is evidence of pollution in the tributaries of the Lake Chad basin. The degrading quality of the major rivers feeding the lake also contributes to the declining water quality of the lake. Several dams built along the Chari-Logone River and the Kamadugu-Yobe River by member states for hydropower generation, significantly reduced and affected the quantity and quality of

water reaching the lake (GIZ, 2015b). The dams reduced the water flow to the lake by over 50% (Olivry *et al.*, 1996; Coe and Foley, 2001; Glantz, 2004; Onuoha, 2008). Dams disrupt and blocks fish migratory routes and affect breeding grounds (Mockrin and Thieme, 2009). Artisanal mining for potash creates sporadic trenches and pit in different land surfaces. After the mining operations, trenches and pits are abandoned without any form of restoration leaving burrows and scars in the open grasslands, thereby reducing flora diversity and grazing grassland for livestock (Raji and Omoyeni, 2005; LCBC, 2015). Waterborne diseases such as malaria, yellow fever, diarrhea, measles, chickenpox, tetanus, and acute respiratory infections are reported to be prevalent in the region among children (Fortnam and Oguntola, 2004).

3.3. Organic Nutrients Pollution

Kolo *et al.* (2010) reported moderate pollution in Lake Chad basin area of Borno State Nigeria with levels of dissolved oxygen (DO) and biological oxygen demand (BOD) that could support aquatic process, but a simple linear regression model indicated a healthy state in the surface waters of Kwatan Dawashe portion of Lake Chad with the analysis of physicochemical parameters such as DO, BOD, chemical oxygen demand (COD) and total organic carbon (TOC), (Gwaski *et al.*, 2013b). Some level of groundwater pollution has been reported in the Lake Chad basin (Vassolo, 2012). About 30% of the groundwater from the aquifer in the lake was quantified and reported not suitable for human consumption (TWAP, 2015). Limited data showed elevated amount of salt, fluoride, nitrates, iron, and manganese in the aquifer, especially on the superficial layers (TWAP, 2015). Also, significant pollution of groundwater has been identified in the aquifer within the Central African Republic and Chad sector of the lake (TWAP, 2015).

Tchadanaye *et al.* (2016) reported some levels of organic pollution in water and sediments of the Chari River, which is a major source of water supply into Lake Chad. The elevated level of organic pollution in the river was attributed to domestic sewage, industrial effluents, and agrochemicals. The discharge of fertilizers via erosion and organic wastes from businesses and small industries such as hotels, slaughterhouses into streams has resulted in the proliferation of phytoplankton and blue-green algae resulting in eutrophication (Raji and Omoyeni, 2005). The preponderance of nutrients in the lake has resulted in the increased growth of aquatic macrophytes which deplete oxygen contents in water and affect aquatic life (Fortnam and Oguntola, 2004).

3.4 Heavy Metals Pollution

Jonathan *et al.* (2016) reported varying concentration of heavy metals ranging from 0.01 to 80877.06 mg/kg in sediments within Dumba and KwataYobe in the Nigerian axis of the basin. Metals such as cadmium, chromium, iron, manganese, lead, zinc, and arsenic were above the permissible limit. This should be of great concern to stakeholders, especially policymakers in member states. Also, Gwaski *et al.* (2013a) assessed the levels of heavy metals (cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc) in tissues (gills, kidney, liver, lung and muscle) of six species of fishes (*Polypterus ansorgii*, *Clarias anguillaris*, *Oreochromis niloticus*, *Synodontis nigrita*, *Bagrus docmac*, and *Lates niloticus*) along the Nigerian axis of Lake Chad. They reported varying levels of elevated heavy metals in tissues of the various fishes especially *Clarias anguillaris* and *Oreochromis niloticus*. On the specific bioaccumulation pattern of the various species of fishes, they reported that *C. anguillaris* preferentially accumulated a higher amount of cadmium, lead and zinc, *O. niloticus* accumulated copper, manganese and nickel, *S. nigrita* and *P. ansorgii* accumulated chromium and iron while *L. niloticus* and *B. docmac* show less accumulative capacity. These commercial fishery products with elevated levels of heavy

metals are directly consumed by locals around the basin and sold in processed form in various markets across neighboring states of the basin. N'garam *et al.* (2017) reported high levels of nickel, iron, and cadmium above international guidelines in Chari River due to domestic, communal, and industrial wastewater discharge, and run-off from agriculture, although, manganese, zinc, chromium, and copper concentration were in the range of permissible limits (WHO, 2008).

3.5 Pesticides Use and Pollution

Vassolo and Daïra (2012) reported high levels of chloride, total dissolved solids (TDS), sulphate and nitrate in groundwater along the Chari-Logone region. The level of pollution was attributed to intensive use of agrochemicals especially chlorinated fertilizers and pesticides in agriculture over a long period of time. Chloride (150 - 350 mg/l), TDS (1,500 - 5000 mg/l), nitrate (50 mg/l) and sulphate (500 - 1000 mg/l) were extremely high in the Chari-Logone region of the basin. The excessive amount of pollutants far higher than acceptable limits found in a few samples in the study area is an indication that the groundwater quality is undergoing significant chemical fluxes from agricultural input. They advocated that hand-dug wells should be abandoned in benefit of drilled, well constructed and protected boreholes. If this is not possible, then better management of hand-dug wells is recommended (Vassolo and Daïra, 2012). Varying pH has been reported ranging from 9.5 to 4. This variation in pH indicated weakly alkaline to strongly acidic conditions in groundwater of the Lake Chad basin (Vassolo and Daïra, 2012).

Crampon *et al.* (2014) investigated the levels of pesticide (Paraquat) in soil exposed to irrigation for over 25 years in Diffa, Niger axis of Lake Chad. They reported Paraquat concentrations ranging from 953±102 to 3083±175 μg/kg at depths of 0.80 and 2.75 metres below the land surface. Paraquat is a persistent pollutant which could persist in soil for several decades, and act as a contact point for pollution and accumulation across the food chain (Crampon *et al.*, 2014).Elevated levels of pesticides and heavy metals have been reported in tissues of fishery resources in the Nigerian axis of the Lake Chad basin. Akan *et al.* (2013) reported elevated levels of organochlorine and organophosphate pesticides in the gills, liver, stomach, kidney, and flesh of *Tilapia zilli, C. anguillaris, Hetrotis niloticus* and *O. niloticus* above national and international limits between the periods of September 2010 and October 2011 at Kwantan Turare, Baga, Borno State, Nigeria. They reported levels of pesticide residues exceeding maximum permissible dietary intake which could pose a serious concern to public health within the basin.

Some of the pesticides applied around the basin are broad-range chemicals that are smuggled across the borders of neighboring countries without proper regulation and adequate control. It is estimated that about 500 to 1000 m^3 per year of pesticides are consumed in Chad with the cotton industry reportedly consuming the largest amounts of pesticides (Akan *et al.*, 2013). Many of the pesticides use in the region are poorly regulated and are classified as highly lethal and detrimental to non-target organisms in the ecosystems. Many pesticides banned in other parts of the world are still very much in use in Africa and some of these pesticides are heavily available for the control of pest in the basin (Keith and Plowes, 1997). The poor enforcement of regulatory frameworks within the Chad basin is also a factor that enhances the proliferation of toxic agrochemicals in the lake region. Although monocrotophos, an organophosphate insecticide has been discontinued in developed countries due to its detrimental effect on birds, however, it is still in use extensively by the cotton industry in Chad (Keith and Plowes, 1997; Fortnam and Oguntola, 2004). Fertilizers and insecticides such as fenitrothion, deltamethrin, lindane and malathion are used extensively by rice farmers across the basin despite their ban as persistent organic pollutants

(Keith and Plowes, 1997; Fortnam and Oguntola, 2004). This is due to the poor regulatory framework for the use of agrochemicals in the region.

3.6 Illegal Fishing Practices

Despite existing fishery regulations, fishers in the Lake Chad basin uses dumba fish trap. The dumba gear, fabricated with small size mesh materials, traps both adults and juvenile fishes thereby depleting the fishery resources of the lake. The trap is a destructive, obnoxious, and unorthodox fishing method that is unacceptable to effective fishery resources management (Agbelege *et al.*, 2002; Raji and Omoyeni, 2005). The poor and ineffective implementation of fishery regulations in member states is responsible for the continued use of such illegal fishing gear in the Lake Chad basin.

3.7 Pollution from Artisanal Mining and Petrochemical Exploration

Artisanal mining of gold and diamond is prevalent in the Tandjile and Mayo-Kebbi regions of Chad which borders CAR. Gold mining has been reported to have a severe public health impact among artisanal miners, particularly children in northern Nigeria (MMSD, 2018). Artisanal miners are reported to use mercury as a binding agent for gold dust in the basin. Mercury is highly toxic and could result in severe pollution of water, soil, flora, and fauna and ultimately affecting public health along the basin. There are active exploration efforts for oil and gas in the Lake Chad basin, especially in the south and center of the basin (LCBC, 2015) and the construction of an oil pipeline in the northern part of the lake (LCBC, 2015). Oil and gas exploration in the Lake Chad basin started 30 years ago after initial analysis of the young tertiary mineral properties of the region. The Borno-Chad Basin is one of the seven frontier basins for oil prospecting in Nigeria (Kalejaye, 2017). The intense activities for oil exploration in the Nigerian sector of the Chad basin were attributed to the discovery of oil deposits in neighbouring countries. Over 2 billion barrels of oil have been discovered in Doba, Doseo and Bangor in Chad Republic. About 10 billion barrels are reported in the Logone Birni in Southern Chad and Northern Cameroun and over 1 billion barrels in Termit-Agadem Basin in Niger Republic (Kalejaye, 2017). The intensive exploration activities in 2017 by the Nigerian National Petroleum Corporation is facilitated by the acquisition of seismic data in 2010 which supports the possibility of the potentials of commercial oil deposits in the basin (Kalejaye, 2017). With a target of 40 billion barrels of proven reserve in 2020, the Nigerian government is keen on meeting the oil reserve target and Lake Chad basin is one of the viable frontier basins with the prospects of attaining such ambitious target. About 23 exploration wells have been drilled in the basin so far in the search for commercial oil and gas. All these activities add to the increasing pollution scenario of the Lake Chad basin. There is a construction of a pipeline through Cameroon to the Atlantic Ocean. The oilfields to be developed are located in the Doba region, a part of the Lake Chad watershed. The pipeline would cross the Mbéré River that feeds into the Logone River and then into the Shari River, as well as several other tributaries of Lake Chad (World Bank 1999; Mockrin and Thieme, 2009). There is a functional refinery in operation along the downstream of the River Chari in Chad (LCBC, 2015). Effluents from the refinery can reach the river and affect the tributaries including Lake Chad.

All activities surrounding the operations in the oil industry can release pollution into the environment. From seismic activities to drilling, production, transport, processing, and consumption of oil results in the generation of human and material wastes, radioactive wastes, produce water, oil spills, etc. (Ekperusi and Aigbodion, 2015). These polluting materials could compound the rising pollution scenario of the basin. The World Bank and its partners have put

mitigation measures in place regarding pollution management for the oil field developments in Chad, CAR and Cameroon (ESSO 1999; Fortnam and Oguntola, 2004). Oil development could result in severe pollution, no matter the environmental management plan that has been provided on paper. The precautionary approach and the polluter pay principle are two instruments that are very difficult to implement in the oil and gas industry in developing countries, as seen in West Africa and South America.

4.0 Restoration and Resource Management of Lake Chad Basin

The ambitious plan and programmes to restoring Lake Chad will be practically impossible without an effective institutional capacity development, improved regulatory framework and sound environmental management policy (LCBC, 1992). Joint and coordinated efforts with players within and outside the region will be needed to create a sound and viable restoration and resource management programme for the survival of the Lake Chad basin.

4.1 Institutional Capacity Development

Recognizing the need to put a coordinated front to tackle the growing problem of the Lake Chad basin led to the establishment of the Lake Chad Basin Commission in 1964. The commission became the institutional vehicle for the management of the lake. Building the institutional capacity of the commission and other related institutions in member states is essential in the effective management of the lake and the basin for sustainable development. The Lake Chad basin is located in one of the poorest and technological deficient regions in the world and the complex technological innovations needed to turn the fortunes of the basin are not readily available among member states.

Over the years, several international development agencies such as the United Nations Environment Programme, United Nations Educational, Scientific and Cultural Organization, United Nations Development Programme, Food and Agricultural Organization, United Nations Department for Economic and Social Affairs, Global Environment Facility and foreign government and their agencies such as the European Union, French Cooperation, German Ministry for Economic Co-operation, and Development (BMZ),

German Development Agency, Gesellschaft für Internationale Zusammenarbeit (GIZ) and dozens of other organizations have made efforts to fund intervention programmes at the Lake Chad basin and provide capacity building including satellite technology, remote sensing, GIS, water resources management, fishery research, etc. for increased capacity and development of the lake. Despite these trainings, more efforts are still needed to bring the required and domesticated capacity in the region for a robust management programme of the basin.

4.2 Institutional and Regulatory Frameworks

Several programmes and policies have been initiated and implemented by the commission and partners in the management of the basin over the years. The commission in collaboration with member states, regional and international institutions has executed programmes towards the management of the basin. Despite these efforts, there is still much to be done to achieve sustainability. Aminu-Kano (2002) examined the political, social and economic contexts and noted that only a well-coordinated and integrated water resources management approach will ensure sustainable natural resources management in the region. The joint environmental audit of the lake instituted by the German Development Agency, GIZ in collaboration with member states

reported some weakness in the regulatory framework for the management of the lake which include (GIZ, 2015a);

1. *The strategic planning for the development of the Lake Chad basin does not allow for a proper connection between the actions and needs of the riparian countries on local, national, and regional level, and the objectives set by the Commission.*
2. *The Commission does not entirely fulfil its purpose as transboundary basin organization, in particular with regard to the equitable management of water, the development of the basin and the enforcement of rules for the protection of water resources, for lack of a clear and specific mandate to do so and of the appropriate organization of the Executive Secretariat's departments.*
3. *The Commission does not ensure the collection, processing, distribution and archiving of data relating to the evolution and use of water resources in the Lake Chad basin, for lack of the appropriate procedures and logistics and of sufficient commitment from the states to contribute to this.*
4. *The Commission does not sufficiently direct its financial, human, and logistical resources towards effective actions of sustainable management and protection of water resources of the Lake Chad basin.*
5. *The Commission's funding model is not sustainable, as it only relies on the contributions of the Member States and support from donors – financing sources that are limited, temporary, and difficult to mobilize.*

Due to the limitations observed, GIZ concluded that the performance of water resources management activities of the commission is seriously threatened (GIZ, 2015a). There is a need for forward thinking to amend the law establishing the commission and the programmes of the commission for effectiveness.

4.3 Environmental Impact Assessment

There is insufficient information, data, and research efforts regarding the level of environmental pollution of water, groundwater, and sediment, soil, and fisheries resources of the basin for national or regional assessment of the true environmental conditions of the entire basin. There is a need for a comprehensive assessment of the current prevailing environmental conditions of the basin, including socio-economic and health issues before any restoration programme is implemented. The impact assessment will provide baseline data for environmental, health, cultural, socio-economic condition of the natural resources and population living in the basin. It will provide data for biological resources such as the diversity of flora and fauna present in the lake and the environmental conditions in respect to the quality of surface and groundwater, soil, and sediments for effective planning. The commission should plan and draw up terms of reference for the assessment based on EIA regulations in member countries of the Chad basin following international principles and regulatory frameworks governing EIA and global best practices. The EIA will provide a vital tool for effective planning and management of the basin. This is important so that in areas where there are substantial pollution and degradation, there is a need for remediation before the restoration of the lake.

4.4 Pollution Remediation

There is a need to implement ecological based remediation programmes in areas where there are known soil, sediment, surface, and groundwater pollution. This is imperative to reduce and eliminate the transfer of pollutants across the food chain to human populations. The nature of the remediation programme will depend on the nature of pollution and the media polluted. Petroleum has become the main energy source for economic development, providing financial resources to several multinationals and the nations of the world, but the case in Africa especially Western Africa is different. Despite its worth, oil in its raw or refined form is toxic to almost all forms of life. The exploration of oil and gas has left a sad tale in many communities, creating conflicts, division, increasing poverty, pollution, and death (UNEP, 2011). There is a need for effective regulation of the oil industry in the Lake Chad basin in other to prevent pollution, manage oil spills, remediate polluted areas and pay appropriate compensation to those affected by the activities of the oil industry.

4.5 Environmental Monitoring and Management

It is imperative to establish monitoring systems for the various components of the environment and natural resources in the basin. Relying on data from institutional and individual research outside the lake or basin is insufficient. Interestingly, Article 7 of the *Water Charter of the Lake Chad Basin* drafted in 2011 stressed the need for the establishment of *"a regular regional water quality surveillance system"* across the basin with a centralize database (LCBC, 2011). The surveillance or monitoring systems require improvements and establish criteria by the commission for the collection of data with a uniform standard across member state for effective planning and decision making for the basin. There should also be a monitoring system for biodiversity and soil for effective management. Article 66 stated that '*A Regional DataBase (RDB) shall be set up henceforth within the Commission and under its authority; the Database shall contain all the data and information on the Basin supplied principally by the State Parties and intended to meet the needs of the Commission, the member States and their partners or any other user. The Regional Database shall be managed by the Lake Chad Basin Observatory*' (LCBC, 2011). There is a need for harmonization of the methods for data collection in member states for the data to be meaningful for analysis, interpretation and policy-making for the benefits of the basin.

4.6 Restoration of Local Species

As part of the restoration plan, adequate provision should be made to restore local flora and fauna. There is a need for a review of previous studies and anecdotal information to understand the diversity of flora and fauna for effective restoration of the local species population. This should be the case for plant and animal species that are facing extinction or with history of complete disappearance from the basin. Ecological restoration of vital areas where it is scientifically feasible, especially the southern axis should be implemented. The re-emergence of vegetation would attract various species into the region. There can also be a reintroduction of animals through captive breeding, capture and release system for crucial keystone species to revitalize the habitat and ecosystem in the region (LCBC, 1992).

5. Conclusion

The Lake Chad basin is a unique ecosystem that has faced a drastic decline as a result of anthropogenic activities over time. Such activities have impacted the lake resulting in depletion and degradation of natural resources and the pollution of various media within the basin. There is a need for a comprehensive assessment of the socio-economic, cultural, health and environmental

matrices to have the relevant data and information to embark on a robust restoration plan and programmes for the lake for effective management and sustainability as we move into the future.

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