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# Identifying anthropogenic 'hotspots' and management of water resources in Lake Chad Basin using GIS

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In order to understand the relationship between population pressure on water resources, and changes in vegetation cover within the Lake Chad Basin (LCB), this paper analyzed demographic and biomass burning footprint using Geographical Information System (GIS) software. An overlay analysis identified anthropogenic hotspots that are likely to define the modification of the LCB in the future. Analysis of anthropogenic dynamics suggests that with a projected population of 51 million in 2015 rising to about 80 million by 2030, the Lake Chad (LC) watershed will be significantly impacted. The spatial characteristic of the anthropogenic footprint shows that sustaining water services will continue to be a problem. The anthropogenic hotspot map generated is thus a useful tool for policy makers to target areas of rapid change with the greatest impact on the size of LC. The proposed inter-basin water transfer will require the most comprehensive urgent policy responses.

**Keywords:** Lake Chad; arid region; inter-basin; population; water resources; hotspots

## Introduction

### *Background*

The Lake Chad Basin (LCB) is located at the transition Sahelo-Sudanian zone between the Sahara Desert and tropical rainforest of West Africa. The decrease in size of Lake Chad (LC) stands out as one of the significant observed changes in the region. The LCB is also located in one of the poorest and most drought prone regions of the world (Global International Waters Assessment [GIWA], 2003). A unique and highly productive basin with exceptional biodiversity, the LCB, is home to about 37 million inhabitants (Fortnam & Oguntola, 2004).

Figure 1 offers the classification of various states of the lake as proposed by Tilho (1928) and Lemoalle et al. (2012). It shows the dramatic decrease in the size of the lake from about 24,000 km$^2$ in the 1950s (Large Lake Chad) to about 18,000 km$^2$ in the early 1970s (Normal Lake Chad) Lemoalle et al. (2012). Drought in the late 1960s to early 1970s led to the splitting of the single lake to northern (Sahara-arid) and southern (Savanna-humid) pools around 1975 (Gao, Bohn, Podest, McDonald, & Lettenmaier, 2011; Lemoalle et al., 2012). Recently Lemoalle et al. (2012), added a new category called a Dry Small Lake Chad with the northern pool permanently dry most of the year.

Our understanding of the LCB hydrology system is still poor (Lemoalle et al., 2012). However, it is influenced by many factors including (1) precipitation (e.g., Olivry,

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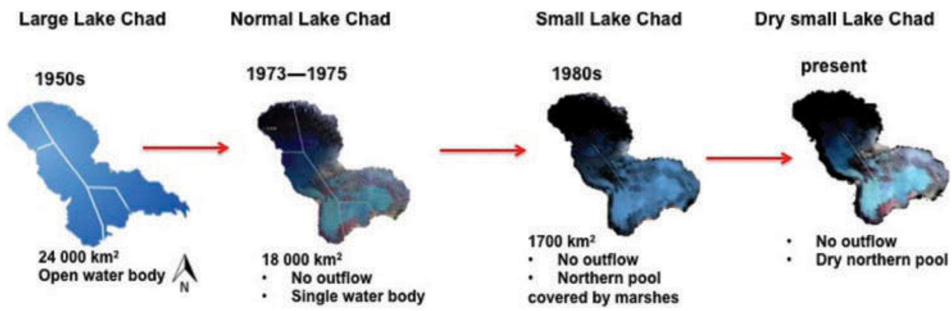


Figure 1. (Colour online) Schematics of the state of Lake Chad showing the decrease in size (modified from Landsat 5 images; Courtesy of NASA. 2001).

Chouret, Vuillaume, Lemoalle, & Bricquet, 1996), which is the key variable linking land surface hydrology to atmospheric hydrology, (2) the amount and seasonality of surface inflow (Famine Early Warning System [FEWS], 1997) from the tributaries, (3) recharge through groundwater flow (Geerken, Vassolo, & Bila, 2010), and (4) anthropogenic effect from increased population pressure (Gao et al., 2011) manifesting as increased water demand through irrigation. According to the International Panel on Climate Change (IPCC) Fourth Assessment Report, decreases in the size of lakes can be attributed primarily to human use and declining precipitation (IPCC, 2007). While precipitation is a critical element that determines the amount of infiltration for groundwater recharge and runoff (river flow) to LC, anthropogenic pressure tilts these natural dynamics and is expected to dominate the LC region. This paper will thus focus on the intersection of the natural and anthropogenic dynamics at play in the LCB while exploring potential alternatives to sustainable water resource management in the LCB.

### *The problem*

The focus on identifying hotspots of anthropogenic activities contributing to the shrinking of LC as well as mapping and management of water resources in the LCB was due to several factors: (1) the impact of desiccation of LC has been devastating due to the dependence of local economies on agriculture, fishing, and livestock production, (2) despite the central role of LC in the livelihood of millions of people in the region, the spatial distribution of population dynamics has not been fully documented, and (3) the developmental/economic impacts of the proposed inter-basin water transfer from the Ubangui Basin to the LCB has received little attention.

The decreased level of LC has huge socio-economic impacts. It has contributed to poverty and underdevelopment. To eradicate poverty and hunger as part of the United Nations' (UN) Millennium Development Goals (MDGs) in this region, the changing dynamic of anthropogenic forces has to be factored-into water resources management. This is especially true since the shrinking of LC, especially through deforestation, represents a zone of critical human activities. This creates environmental hotspots.

The relationship between deforestation and hotspots has been studied (Hansen et al., 2008; Myers, 1988). Myers (1988) first defined hotspots of biodiversity as areas that are rich in species. Generally, a hotspot is a center of high activity within a larger area of low activity. Here, we define an anthropogenic hotspot as an area within the LCB where changes in land use and cover from interaction with human beings is contributing to the shrinking of LC. However, linking the behavior of individuals and communities to pixels at the appropriate spatial and temporal scales to demographic and geophysical indicators that define landscape is a challenge in remote sensing and geographical information system (GIS) software (Walsh, Entwisle, & Rindfss, 1999).

While the shrinking of LC as a result of persistent drought has been studied repeatedly, one issue has received little attention: the effect of increasing population pressure on water resources in the LCB. The objective of this study is therefore to identify anthropogenic hotspots that are likely to define the modification of the LCB in future and to analyze the impact of a 3% population increase (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2007). Analysis will focus on the interactions between population pressure, drainage networks, and changes in land use cover. To our knowledge, this is the first time the anthropogenic hotspots of the LCB will be identified. Their relative importance will inform our policy suggestions.

The paper is organized as follows: the datasets and methodology will be described in the next section. The third section presents and discusses the results of the analysis. The final section suggests some innovative technology-policy options for effective water resources management in the LCB.

### *Dataset and methodology*

To depict the LC watershed dynamics and characterize the natural and anthropogenic forces contributing to the shrinking of the lake, the study will use three primary sets of data: (1) topographical data, (2) burnt area (footprint from biomass burning), and (3) population data. We will use GIS software to display the spatial distribution of surface intermittent and perennial rivers, basin topography, dams and population density in the LC watershed.

An anthropogenic variable for characterizing population dynamics was obtained from the 2015 estimated global population density map (Salvatore et al., 2005). This data is freely available at the Food Insecurity, Poverty and Environment Global GIS Database (FGGD). This is a global raster data layer that represents population density grids per square kilometer with a resolution of 2.5 arc-minutes. Each pixel contains an estimated value of number of persons per square kilometer in 2015, obtained by applying population growth trends to population counts for the lowest subnational administrative unit for which 2000 population data were available. The Food and Agricultural Organization (FAO) describes the method used to generate this data layer in Salvatore et al. (2005) and it involves mapping global urban and rural population distributions (Salvatore et al., 2005). The projected 3% population increase used in this study is based on a 2007 United Nations Educational, Scientific and Cultural Organization estimate (UNESCO, 2007). The 3% population increase provided insight on the future population size in LCB.

The shape files for topographical features were obtained from the African Water Resource Database datasets (Jenness, Dooley, Aguilar-Manjarrez, & Riva, 2007) downloaded from FAO's GeoNetwork GIS portals. The anthropogenic footprint on land cover through biomass burning were obtained from the Global Burnt Area-2000 initiative (Tansey et al., 2004) time series of coarse resolution satellite imagery from Satellites Pour l'Observation de la Terre or Earth-observing Satellites (SPOT). The remotely sensed multispectral data from the SPOT satellite has a spatial and temporal resolution of 20 m and three days respectively. Burnt area is defined as areas affected by fire within a specified interval as detected by satellites (Giglio, Loboda, Roy, Quayle, & Justice, 2009). The burnt area's footprint used in this study is not the only driving mechanism but a significant one in terms of anthropogenic footprint in the study area.

The potential anthropogenic hotspots that contribute to the shrinking of LC were identified using spatial GIS operations-overlay analysis that provides a composite picture of the areas of interest. It combines two parameters: burnt area and population density for each grid cell. Here, we have used the local maximum approach where all the parameters are assigned equal weights. The map generated is a shape file representing an anthropogenic hotspot that contains the attributes of both layers based on the intersection of their common attributes.

Ancillary data used in this work also includes the 1973–2010 LC surface water level. Recently, Lemoalle et al. (2012) used a combination of hydrological model, satellite and field data to reconstruct the past levels of LC. The satellite measurement was from Topex/Poseidon satellite, a joint NASA/CNES (National Aeronautic and Space Administration/Centre National d'Etudes Spatials, France) altimetry mission launched in 1982. The northern and southern pools of LC water levels were digitized from this hydrological modeling study by Lemoalle et al. (2012) to compensate for years with no data from Topex/Poseidon satellite. The figures from Lemoalle et al. (2012) were scanned as a raster image that is then digitized using GIS. The digitization was carried out using point mode operation at maximum annual lake level. Post-processing was applied to the digitized map by checking lake levels against the source figure for accuracy. The digitized data was used in the ground-water vulnerability analysis.

The records for the southern and northern pools at Kalom and Kindjeria respectively (Figure 2), were based on the estimate at Bol and model reconstruction. In this study also, we used long-term monthly gridded (0.5 × 0.5 lat–lon) precipitation datasets (version 3.01) from the University of Delaware (UDel), produced by the Center for Climatic Research, University of Delaware (Legates & Willmott, 1990a, 1990b). Data were obtained from http://www.esrl.noaa.gov/psd/data/gridded/data.UDel_AirT_Precip.html.

As part of data preparation, we applied area weighted averaging to the UDel gridded monthly time series for July, August and September (JAS). This has the advantage of minimizing the spatial data gaps in a semi-arid region. Due to the split of LC into North and South Basins, we used annual average index correlated with aggregated annual rainfall totals in the northern and southern LCB (the white line across the LCB in Figure 2a). The aggregated rainfall allowed us to focus on accumulated precipitation thereby reducing the noise from long periods of dry spells characteristic of this region.

## Results and discussion

### *Topography-population association*

Figure 2 shows the geographical, topological, and some hydrological reference of the LCB. The Geographical Information System generated the depiction of the spatial distribution of the elevation, the perennial and intermittent surface waters, and the freshwater marsh. Figure 3a shows the three major tributaries: the Chari, Logone, and the Komadugu-Yobe Rivers. The Chari River, according to the Famine Early Warning System (FEWS) (1997) report, transports more than 90% of the discharge to LC (FEWS, 1997). By way of contrast, the Komadugu-Yobe River and a few others discharge less than 10% (FEWS, 1997).

Figure 3a shows the possible association between these major tributaries, topographical characteristics, and the spatial distribution of population density. Figure 3b shows the

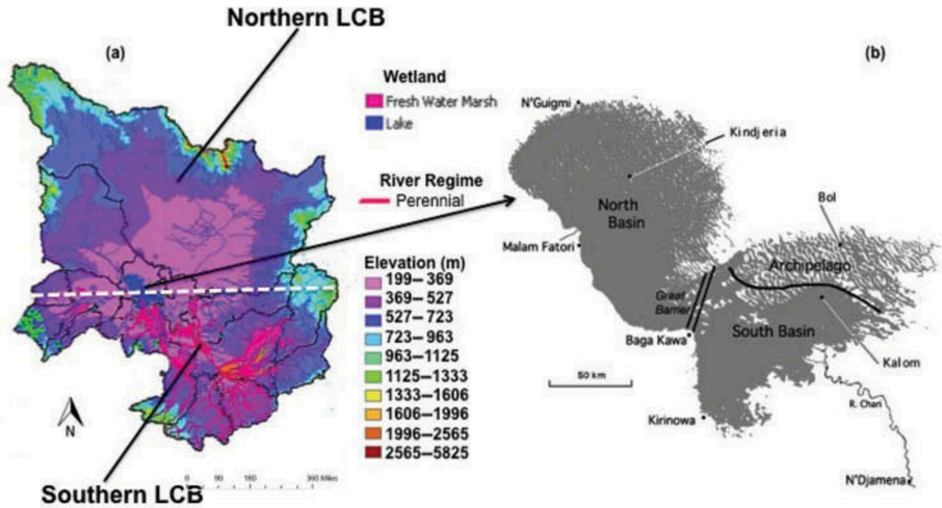


Figure 2. (Colour online) (a) Geographical, topological and some hydrological reference of the LCB showing the freshwater marsh, elevation (meters) and the perennial rivers. (b) Lake Chad showing the major tributary – Chari River, the North and South Basins, Kalom and Kindjeria lake-level observation sites (Lemoalle et al., 2012).

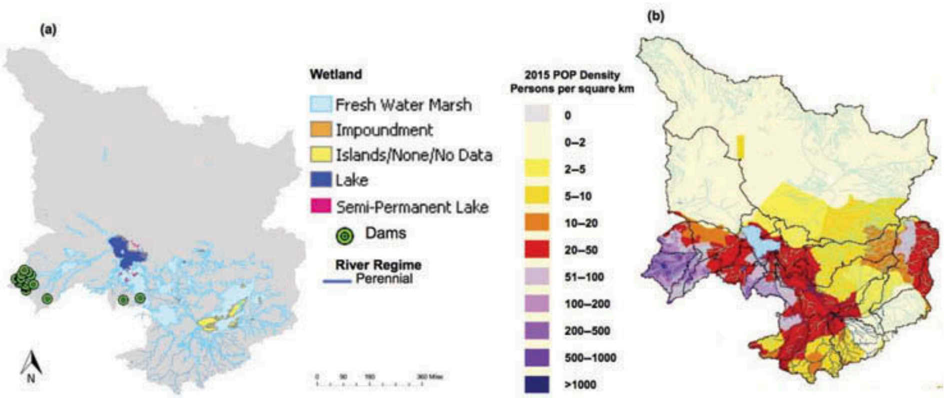


Figure 3. (Colour online) (a) LCB surface water hydrology showing Lake Chad (blue), the semi-permanent lakes (red), islands and dams. (b) 2015 population density showing the number of persons per square km for the LCB.

2015-projected population density per square kilometer. The population patterns provide a rough estimation of human-land ratio of various spots within the LCB. The extremely uneven distribution of population in the LCB is correlated with the spatial distribution of surface water bodies within the basin. The northeast and northwest parts of the LCB are characterized by intermittent water bodies and a sparse population while the southern parts have perennial rivers that act as lifelines to agricultural activities and human needs for the dense population (Figure 3). This association demonstrates a strong influence of geomorphology on population patterns and points at possible areas of anthropogenic pressure in the watershed. The association also suggests that a gradual change in the surface water distribution will have impact on the distribution of population pressure in the basin.

### *Hotspot analysis*

Figure 4a shows the output from the overlay analysis integrating the 2015 population density data with burnt area in order to identify anthropogenic hotspots that contribute to the shrinking of Lake Chad. Figure 4b shows the hotspot pyramid according to *the Committee on Environment and Natural Resources* (CENR) research 2001 classification. Each level in the pyramid is a potential area where changes in land use impinge on the ecological health of the environment.

In this hotspot analysis, we have divided the LCB into six categories, very low, low, medium, high, very high and extremely high (Figure 4a); based on the weights of the joint attributes of population per square meter and burnt area generated from the GIS overlay analysis. Clearly, anthropogenic hotspots occur at multiple spatial and temporal scales in the LCB and often differ among sub basins. Kano City has the highest anthropogenic hotspot index – very high – while Bongor, Maiduguri, N'Djamena, and Diffa are medium index (Figure 4a). The driving force in the central-south of the LCB appears to be settlement expansion driven by population growth in N'Djamena and pastoral operations in Bongor and Massenya (Figure 4a). This constitutes the environmental changes and land transformation processes in the hotspot pyramid (Figure 4b). These land transformation processes usually result in a low aridity index (AI) leading to low moisture availability for the potential growth of vegetation (Okonkwo, 2011). There is also low soil water holding capacity and subsequently high drought vulnerability. The physical manifestation of this low aridity is desert encroachment in the hotspot pyramid.

In response to the reduced availability of freshwater resources, communities living on the banks of feeder rivers in these hotspots may resort to diverting rivers for irrigation purposes. The concentration of dams around Kano municipal (Figure 3a) is an indication of human interruption to the natural flow patterns of rivers. It is linked to the decreased inflow of the Komaduyu River to LC and represents the critical zone in the hotspot

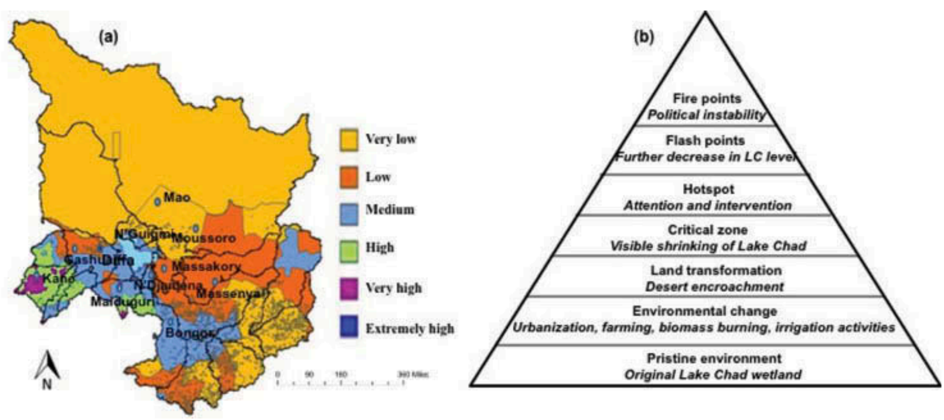


Figure 4. (Colour online) (a) LCB anthropogenic hotspot model output. (b) Hotspot Pyramid (modified from Glantz, 2003).

pyramid (Figure 4b). This pressure has tilted the natural dynamics and is expected to dominate the LC region. This anthropogenic diversion of rivers in densely populated Kano points to a possible extension of dam construction in other sub-regions with sparse population. The attention and intervention in the form of inter-basin water transfer is a confirmation of the classification of the LCB as an environmental hotspot. Kano is therefore, probably one of most critical areas in the region with a potential of reaching a flash point level in the pyramid. Accommodating this growing population in the LCB requires an awareness of the impact of the spatial distribution of population density of water resources. The visible change in the size and level of both southern and northern pools of LC represents the critical zone in the hotspot pyramid (Figure 4b).

Figure 5 shows the time series of precipitation in the Northern and Southern Basins and LC levels at Kindjeria and Kalom of the 'Dry Small' LC. The rainfall in northern LCB shows large variability with less than 4 cm total accumulation in the peak of the rainy season in 1984 corresponding to one of the severe droughts that have plagued the Sahel region. In southern LCB too, in 1984 the impact of the early 1980s' severe drought is pronounced.

There was a continuous decrease in the level of LC from 1979 to 1985 in the northern pool. In the southern pool, the decrease in the lake's level from 1979 to 1985 is less dramatic and attributed in part to decreased inflow from the Chari River, which is the main tributary to LC (Nami, 2002).

Also, the time series of rainfall in the North Basin and South Basin display common variability from 1972 to 2010 with the exception of the spike in rainfall in the Northern Basin in 1994. There appears to be some recovery in rainfall from the year 1999 in northern LCB and around 1991 in southern LCB corresponding to the onset of recovery in Sahel rainfall as reported by Nicholson (2009). The minimum rainfall in 1984 coincides

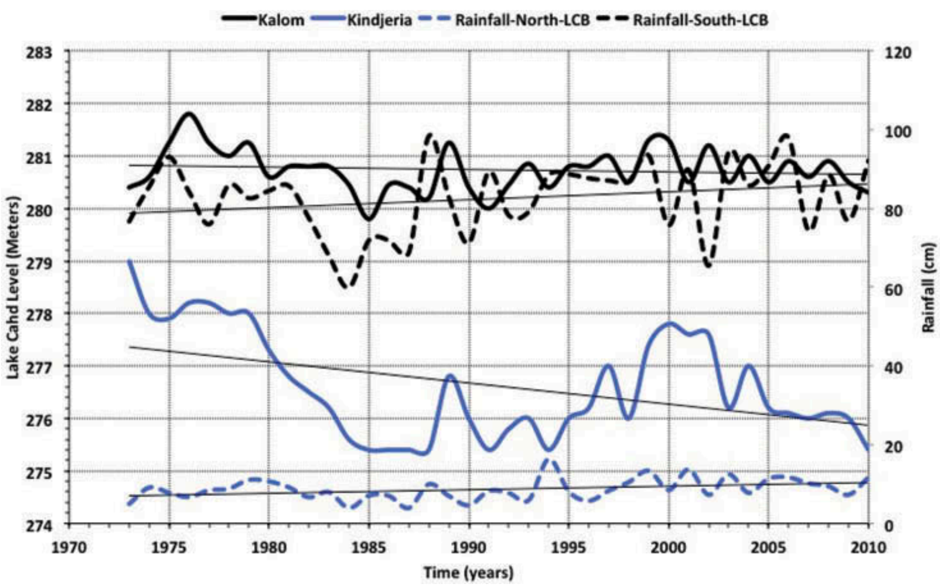


Figure 5. (Colour online) Time series of JJA accumulated precipitation at Northern LCB, Southern LCB and Lake Chad level at Kindjeria and Kalom.

with minimum lake levels in the North and South pools of LC. Even when Lake Chad is a closed basin, it is still linked to groundwater (e.g., Geerken et al., 2010; Isiorho, Matisoff, & Wehn, 1996). As such, the lake level is significantly affected by anthropogenic pressure through groundwater extraction. However, a closer look at the LC level from 2005 at Kindjera shows a decreasing lake level even with increasing precipitation. Similarly, there is a decrease in lake level at Kalom around 2008/9 with increasing precipitation. This anomaly in the LC level can be attributed groundwater drawdown due to human demand.

The shrinking of the lake marked a critical stage, as shown in the pyramid (Figure 4b), and has generated worldwide attention as a degraded ecological system linked with climate change. Dry Small Lake Chad, with the northern pool permanently dry, represents an environmental hotspot and had also been generating much attention. The condition has spurred more research on the possible causes, adaptation, and mitigation. Presently, cultures and ecosystems within the LCB are increasingly being threatened. Any further significant decrease in the size and level of the lake may trigger a flashpoint where political instability can start within the LCB due to conflict from water use, collapse of the local economy, and the extinction of threatened species. This identification of anthropogenic hotspots is thus useful in targeting areas of rapid change with greatest impact on the size of LC, mainly on the southwest and southeast parts of the LCB. Especially important from the model output is the spatial pattern of the hotspots around the city of Kano. While urbanization may not have a unique spectral footprint, the intersection of high population density with burnt area gives an indication of likely patches of development spreading from the urban fringe.

### *Projected anthropogenic impact on water resources availability*

Figure 6 shows the basin-scale dynamics that regulate the variability in LC level and size. The flow chart conceptualizes interplay of natural climate variability represented by rainfall and anthropogenic externalities. There are two schools of thought on the dominant hydrological mechanism that controls variability of LC level. One is that LC level decreased primarily due to decrease in precipitation, particularly the 1970 and 1980s' drought (Olivry et al., 1996). This theory is depicted in the flow chart (Figure 6) by the wet and drought years that lead to increase and decrease in the lake's level. The second opinion has to do with groundwater seepage to and from the lake depending on season (Roche, 1980). The lake is recharged by groundwater during dry seasons while the aquifers are recharged by the lake in pre-drought situations (Geerken et al., 2010).

These two mechanisms are nevertheless strongly linked in the hydrologic cycle, especially in a closed lake like LC. The physical terrain of the LCB with mountainous ranges at the borders means that precipitation ultimately recharges the lake either through surface flows by way of the tributaries or through infiltration-ground water recharge. The external impact of the anthropogenic forces at play in the basin is critically important in these hydrological dynamics.

Based on a 3% increase (UNESCO, 2007), the population in the LCB is projected to be about 51 million in 2015, rising to 60 million by 2020. By 2030, the population is projected to be around 80 million. Kano in the southwest has the highest hotspot index within the LCB, with a population of 9.38 million in 2006 and projected increase to 11 million in 2015.

Already, Carmouze (1983) and Isiorho et al. (1996) have documented the groundwater recharge from LC to the phreatic aquifers southwest of the LCB. Also, the Komadugu-Yobe River now flows for six months instead of nine (Neiland & Bene, 2003). To meet

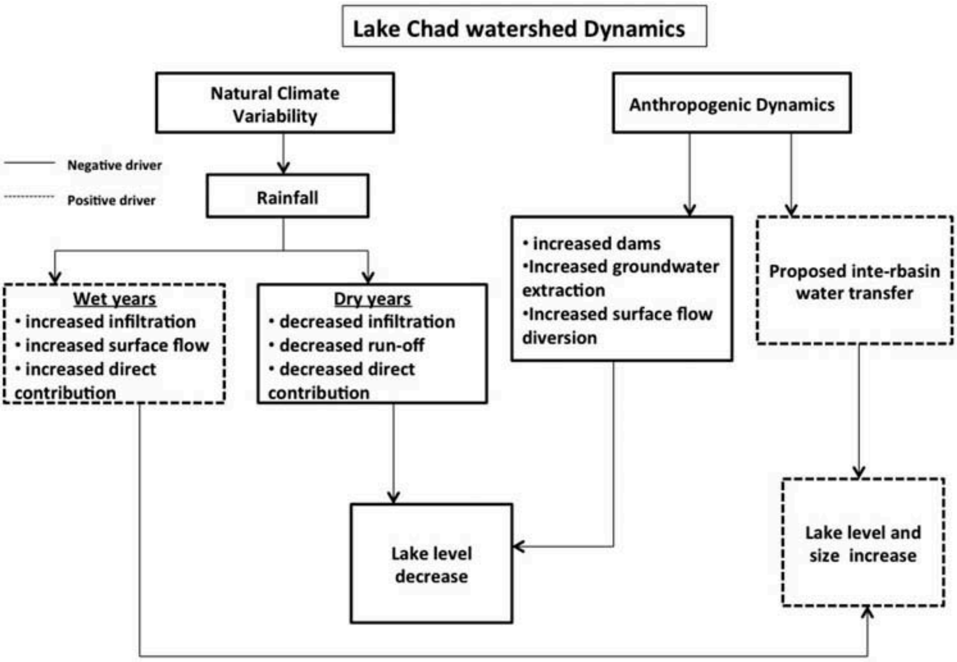


Figure 6. Simplified flow chart of natural and anthropogenic dynamics at play in the LCB.

increasing water demand, more dams may be constructed or the rate of groundwater withdrawal increased to meet additional demand. The natural hydrologic response to these externalities will be an increase in water seepage from LC since the lake is at a higher elevation than aquifers in the southwest LCB.

Another important note of concern from the hotspot map in the context of spatial distribution of projected population is that the central south LCB will see significant increase. This part of the LCB is a critical zone since about 96% of surface recharge to LC comes from the Chari River. With this rapid growth in population follows other significant land use changes associated with an increase in urbanization and changes in land surface properties. The projected cumulative impact on forest cover includes habitat destruction leading to loss of biodiversity, agricultural land, and forest resources. There may also be loss of wetland, modification of aquatic flora and fauna, and increased sedimentation due to reduction in stream flow.

While the complexity of the ecological and anthropogenic dynamics make it difficult to be exact, the above analysis suggests that a worsening situation may degenerate to a flashpoint if nothing is done. Also, while the negative externalities like increase in water abstraction, diversion, dam construction, and changes in land use leads to reduced inflow to the lake, the positive externality through the proposed inter-basin water transfer (Figure 7) will increase inflow into the lake. The vital question now is: 'What can we do with the documented evidence of the intensity of human alteration of natural water resources dynamics in the LCB?' The expected positive impact of the proposed inter-basin transfer right now appears to be the most comprehensive urgent policy option that will address the challenges of sustainable water resources management in the LCB. The next section will focus on moving beyond the analysis of the causes to risk management.

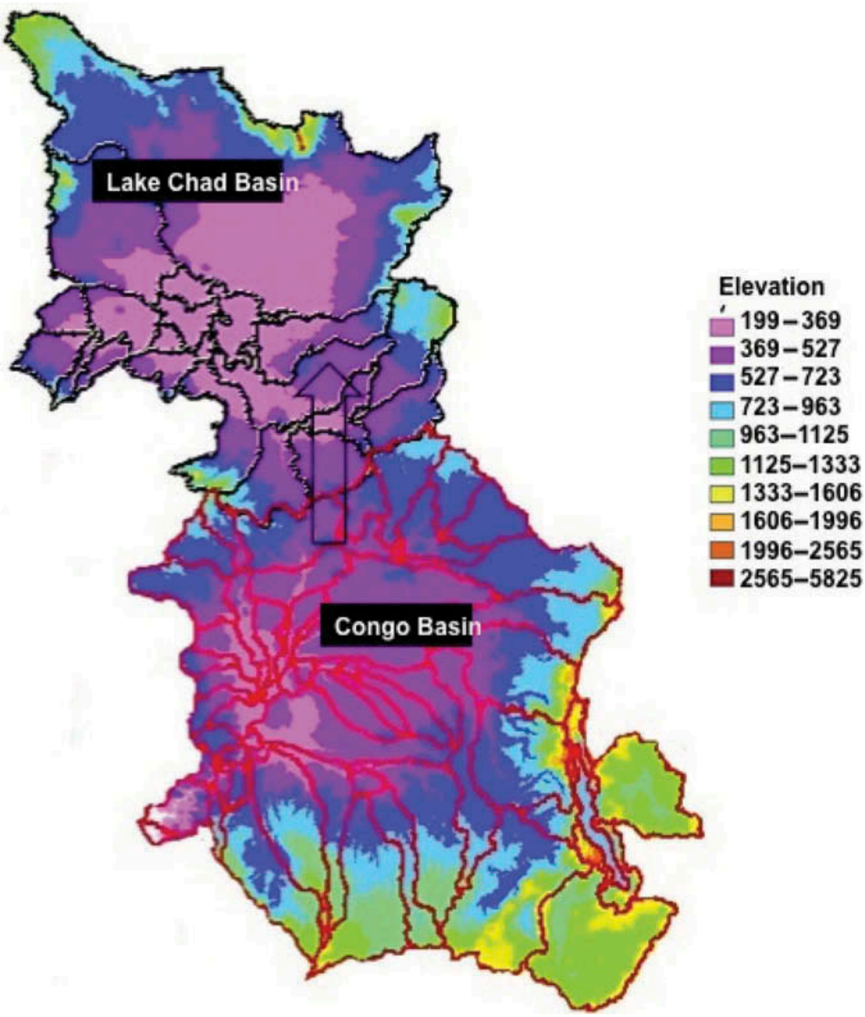


Figure 7. (Colour online) Lake Chad and Congo watershed showing elevation and possible point for inter-basin water transfer (black arrow).

## Policy options

### *Inter-basin water transfer*

This section will focus on mitigation of socio-economic drought as part of integrated water resources management in response to anthropogenic pressure on water resources in the LCB. The failure to manage effectively the available water resources within and around the LCB to meet water and food demand constitutes what Sánchez et al. (2000) described as socio-economic drought. Tackling this condition requires a framework that addresses the environmental and political-economic issues in the inter-basin water transfer from the Ubangui Basin to the LCB (Figure 7). The Canadian firm CIMA International recently submitted a preliminary assessment report on the feasibility of the inter-basin transfer in 2011 (Appolinaire, Soumaïne, Borgoto, & Simon, 2012) while awaiting the environmental impact assessment. One positive note from the preliminary report is the possible increase in the lake's level by one meter in the south and north basins, resulting in approximately 5,500 square kilometers in the size of the lake (Lake Chad Basin Commission [LCBC], 2012).

Appolinaire et al. (2012), had proposed an option of water transfer through the construction of a retention dam at Palambo (upstream Bangui) and subsequent discharge through gravity to the feeder channel of Chari. Figure 7 shows the topography of the receiver (the LCB) and donor (CB) basins. The lowest elevation (dark black arrow) between the two basins is 369–527 meters above sea level while the lake occupies the lowest part of the LCB. This region of low elevation provides a less mountainous terrain of bedrock geology in the inter-basin boundary through which the proposed transfer is expected to take place. A potential disruption in the ecological balance is however still evident from the mountainous terrain at the border of the donor and receiver basins. Care should therefore be taken to guard against additional anthropogenic hotspots in the course of cutting through the mountainous terrain.

It is necessary at this point to highlight some of the potential pros and cons of the proposed inter-basin transfer. The steep point of transfer is advantageous since water can be distributed downstream by gravity through the Chari River once a sizable channel is cut through. This will improve irrigation activities and base flow, especially in times of drought in the basin. However, potential adverse effects of the proposed inter-basin transfer as reported by Appolinaire et al. (2012) include the transfer of biological and physico-chemical constituents from the donor basin (Oubangui) to receiver basin (the LCB). This could threaten aquatic biodiversity through the introduction of invasive species that are not natural to the receiver basin. Also, the Oubangui Basin can experience reduced flow and changes in the hydrological regime, altering species abundance.

For the receiver basin, water-logging, increased erosion and subsequent loss of floodplains especially at the fertile soils around the steep slope in the southeast of the LCB, changes in land-use, and possible introduction of invasive species will all have some negative effect on crop production. Overall, a reversal of the shrinking of LC by this transfer presents a 'bright spot' that can prevent the worsening socio-economic crisis from creating a flashpoint.

### *Pathway to sustainable growth and development*

This section will highlight developmental policy options that will serve as a pathway to sustainable growth and development. Figure 8 shows the schematic of a conceptual model for adaptive capacity and sustainable development for the LCB. In the preceding sections we discussed the mitigation strategy in managing drought and providing adequate water resources in the LCB through irrigation. However, this strategy presents a unique opportunity of developing irrigation agriculture as well as enhancing economic growth and infrastructural development in the region.

Sustainable agricultural development is a panacea for achieving rural development. However, a reflection on agricultural performance in Sub-Saharan African (SSA) countries shows that the region is well behind other regions of the world in terms of irrigated agriculture (Munthali, Mkandawire, & Tembo, 2012). According to the 2004 New Partnership for Africa's Development (NEPAD) report, there was 1,230 kg/ha in cereal yield in Africa against 3,040 kg/ha for Latin America and 5,470 kg/ha for the European Union (New Partnership for Africa's Development [NEPAD], 2004). This disparity in crop production in Africa particularly the Sahel region compared to other regions of the world is partly due to scarcity of water resources. As mentioned earlier, the LCB is located

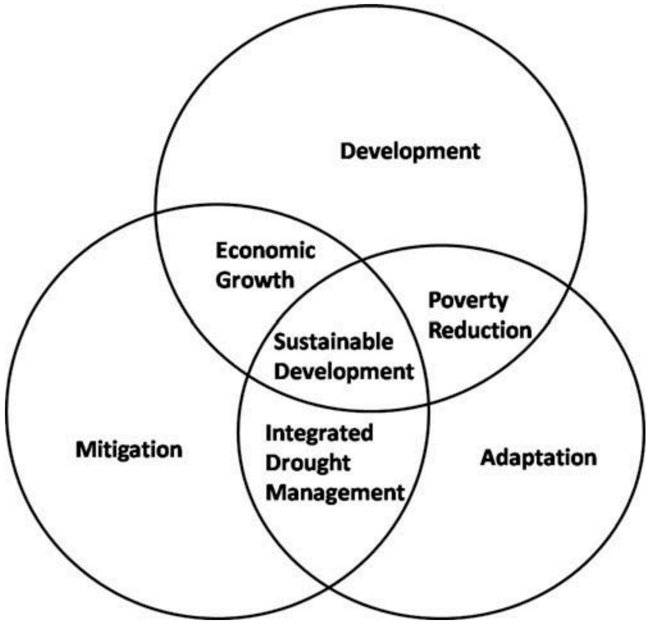


Figure 8. Conceptual model for adaptive capacity and sustainable development for the LCB.

at the transition Sahelo-Sudanian zone, as such, it responds to both dry climatic forcing (harmattan wind) (Knippertz & Fink, 2008) from the north and wet forcing from the south (West African monsoon). The short rainy season (June, July, August, and September) and longer dry spell is a pronounced characteristic of spatial temporal distribution of rainfall in the LCB (e.g., Nicholson & Selato, 2000; Okonkwo, Demoz, & Onyeukwu, 2013). For example, the mean annual rainfall climatology of the LCB varies from 1,500 mm in the southern edges to less than 100 in the north (Okonkwo et al., 2013). Farmers in this region thus receive less amount and duration of rainfall that cuts short the planting season and increases vulnerability to drought climate variability.

Irrigated agriculture through improved technologies is thus pivotal to sustainable growth and development in the LCB. Irrigated agriculture will not only reduce vulnerability to drought, it will also increase the agricultural production and economic base of the farmers. The wider developmental implications of this include: food security, good yield, agricultural income and vibrant local economy as well as poverty reduction.

The second developmental component is meeting the challenges of energy poverty, which has diminished the region's productive capacity. Energy supply is given as a target indicator for achieving the seventh objective of the MDGs, which is to ensure environmental sustainability. But in SSA, only 28% of households (excluding South Africa) have an electrical service; biomass and coal are the primary cooking fuel for over 75% of the population and account for 58% of all energy use (IPCC, 2007). The challenge facing this sub region is not just to increase energy consumption per se, but also to ensure access to cleaner energy services, preferably through efficient and renewable energy, thus promoting sustainable consumption. Expectedly, one of the primary objectives of the inter-basin water transfer is to 'generate 700MW of electricity through hydropower' (LCBC, 2012). Since this region has some hydro-potential – though small and subject to disruptions due to drought, it nonetheless presents a pathway to achieving the NEPAD vision. This potential hydropower resource is a cheaper power source that will minimize environmental hazards while ensuring sustainability.

The trans-boundary irrigation project also presents an excellent opportunity to complement the potential of using renewable water resources to generate electricity. The generated electricity will provide a low carbon alternative that will drive economic growth and development in the region. The hydropower can also be used for running the irrigation system where flow by gravity is inadequate. Irrigation development also has some positive impacts on social and environmental development, such as improvement in health, nutrition, and hygiene. Unlike most industrialized countries that progressed from traditional energy to unsustainable conventional energy consumption patterns, and which are now struggling to move to a sustainable energy path, this region could and should leapfrog directly from current traditional energy consumption patterns to sustainable energy options.

## Summary

Regional population growth and increasing demand for water resources in the LCB necessitates an understanding of the relationship between population pressure, drainage networks, and changes in vegetation cover within the LCB. In this paper, the anthropogenic hotspots that are likely to define the modification of the LCB were identified and the projected impact on water resources availability in the basin analyzed.

The spatial characteristic of the anthropogenic footprint in the LCB shows that sustaining water services will continue to be a problem and that comprehensive water resources management will require sophisticated technologies. The changes in atmospheric dynamics that control rainfall in the LCB cannot be manipulated. But the anthropogenic contribution through changes in land use as well as surface and ground water extraction because of increasing population pressure can be addressed. Farming practices, groundwater extraction, biomass burning, irrigation activities, and pressure from increasing population south of the LCB should be getting adequate attention now.

The proposed inter-basin water transfer provides a forward-looking approach serving as an appropriate drought technology that will not only advance agricultural drought preparedness in the LCB but also enhance economic growth and infrastructural development in the region. The expected benefits of this inter-basin transfer notwithstanding, consideration must be given to the apparent environmental risks associated with disruption of the unique ecosystem in both basins. Other unintended non-economic, cultural and social consequences should be seen as a potentially negative factor and adequate provision for mitigation factored into the overall cost of the project. Another limitation of this study is the use of 2015-projected spatial distribution of population density. As anthropogenic pressure continues to drive increasing water demand and LC level variability, it is imperative to accurately capture such baseline data needed to assist the policy decision. Under long term planning and further research, there is the need to evaluate critically the impact of the proposed water transfer so as to minimize expansion of the anthropogenic footprint in the basin.

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