Journal of Hydrology 540 (2016) 106–128

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

# Spatio-temporal variability of droughts and terrestrial water storage over Lake Chad Basin using independent component analysis

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ARTICLE INFO

*Article history:*
Received 17 February 2016
Received in revised form 25 May 2016
Accepted 28 May 2016
Available online 4 June 2016
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Alon Rimmer, Associate Editor

*Keywords:*
TWS
Soil moisture
ICA
SPI
Drought
Rainfall

SUMMARY

Lake Chad has recently been perceived to be completely desiccated and almost extinct due to insufficient published ground observations. Given the high spatial variability of rainfall in the region, and the fact that extreme climatic conditions (for example, droughts) could be intensifying in the Lake Chad basin (LCB) due to human activities, a spatio-temporal approach to drought analysis becomes essential. This study employed independent component analysis (ICA), a fourth-order cumulant statistics, to decompose standardised precipitation index (SPI), standardised soil moisture index (SSI), and terrestrial water storage (TWS) derived from Gravity Recovery and Climate Experiment (GRACE) into spatial and temporal patterns over the LCB. In addition, this study uses satellite altimetry data to estimate variations in the Lake Chad water levels, and further employs relevant climate teleconnection indices (El-Niño Southern Oscillation-ENSO, Atlantic Multi-decadal Oscillation-AMO, and Atlantic Meridional Mode-AMM) to examine their links to the observed drought temporal patterns over the basin. From the spatio-temporal drought analysis, temporal evolutions of SPI at 12 month aggregation show relatively wet conditions in the last two decades (although with marked alterations) with the 2012–2014 period being the wettest. In addition to the improved rainfall conditions during this period, there was a statistically significant increase of 0.04 m/yr in altimetry water levels observed over Lake Chad between 2008 and 2014, which confirms a shift in the hydrological conditions of the basin. Observed trend in TWS changes during the 2002–2014 period shows a statistically insignificant increase of 3.0 mm/yr at the centre of the basin, coinciding with soil moisture deficit indicated by the temporal evolutions of SSI at all monthly accumulations during the 2002–2003 and 2009–2012 periods. Further, SPI at 3 and 6 month scales indicated fluctuating drought conditions at the extreme south of the basin, coinciding with a statistically insignificant decline in TWS of about 4.5 mm/yr at the southern catchment of the basin. Finally, correlation analyses indicate that ENSO, AMO, and AMM are associated with extreme rainfall conditions in the basin, with AMO showing the strongest association (statistically significant correlation of 0.55) with SPI 12 month aggregation. Therefore, this study provides a framework that will support drought monitoring in the LCB.



## 1. Introduction

Lake Chad Basin (LCB), the world's largest interior drainage basin, covers an approximate area of 2,500,000 $km^2$ and supports an estimated 37 million people who depend on its water resources for agriculture, fishing, and other domestic applications (e.g., Coe and Birkett, 2004; Leblanc et al., 2003). The basin is geographically bounded by latitudes 6°N and 24°N and longitudes 7°W and 24°E (Fig. 1) and is occupied by Lake Chad at the centre, a prominent freshwater body, which largely forms the live wire of the basin's hydrology. The historic and dramatic decline in the spatial extent of the Lake from 24,000 $km^2$ in the 1950s to segmented open water pool of approximately 1700 $km^2$ (i.e., about 90% decline) in recent times, has been reported (see, e.g., Wald, 1990; Birkett, 2000; Coe and Foley, 2001; Leblanc et al., 2003; Lemoalle et al., 2012). Lake Chad receives its water supply primarily from the Chari–Logone river, which provides approximately 95% of the total inflows into the southern pool, and also the Komadugu-Yobe River (see Fig. 2), which provides less than 2.5% of water that flows into the northern pool of the Lake (Birkett, 2000; Coe and Birkett, 2004). In relation to other Lakes in Africa, recent illustration of Lake Chad

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http://dx.doi.org/10.1016/j.jhydrol.2016.05.068

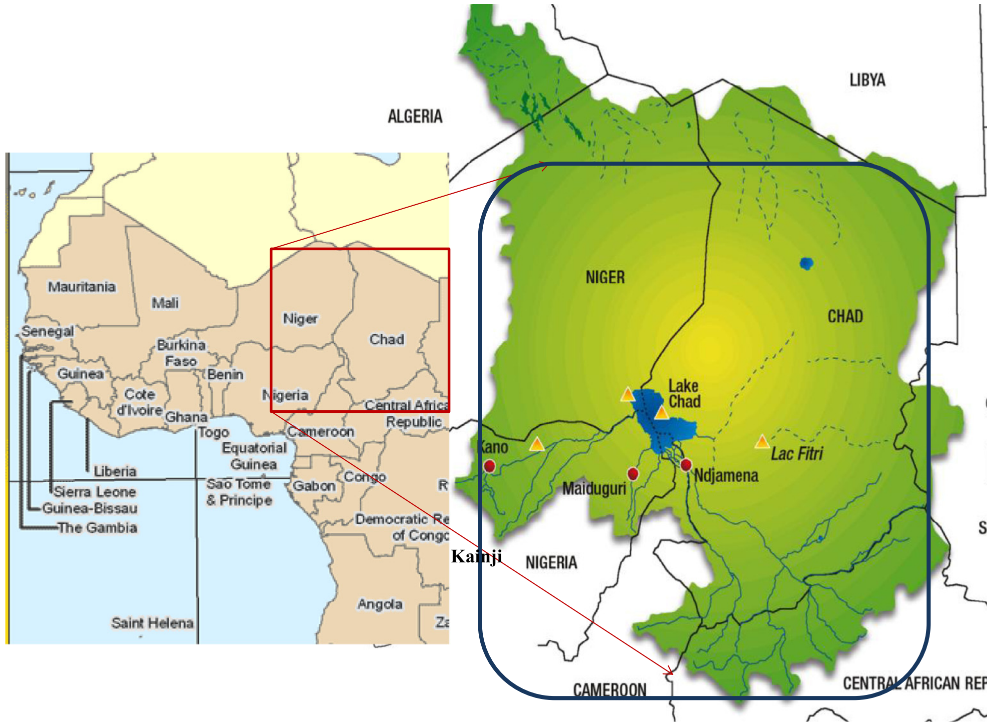


**Fig. 1.** Study area showing Lake Chad, the riparian countries that constitute the Lake Chad Basin, and important river networks (blue line) within the basin. Our analysis focuses on the conventional basin area (a subset of the blue polygon), which includes mostly southern and north eastern sections of Niger, Chad, north-eastern Nigeria, northern Cameroon, and most parts of Central African Republic. Maps are adapted from www.worldmap.org and http://assets.panda.org/img/original/chadmap.gif. The LCB lies at the south western crossroads of the Sahel and forest savanna, a transition zone between the Sahara Desert and the tropical savanna of West Africa (Okonkwo et al., 2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

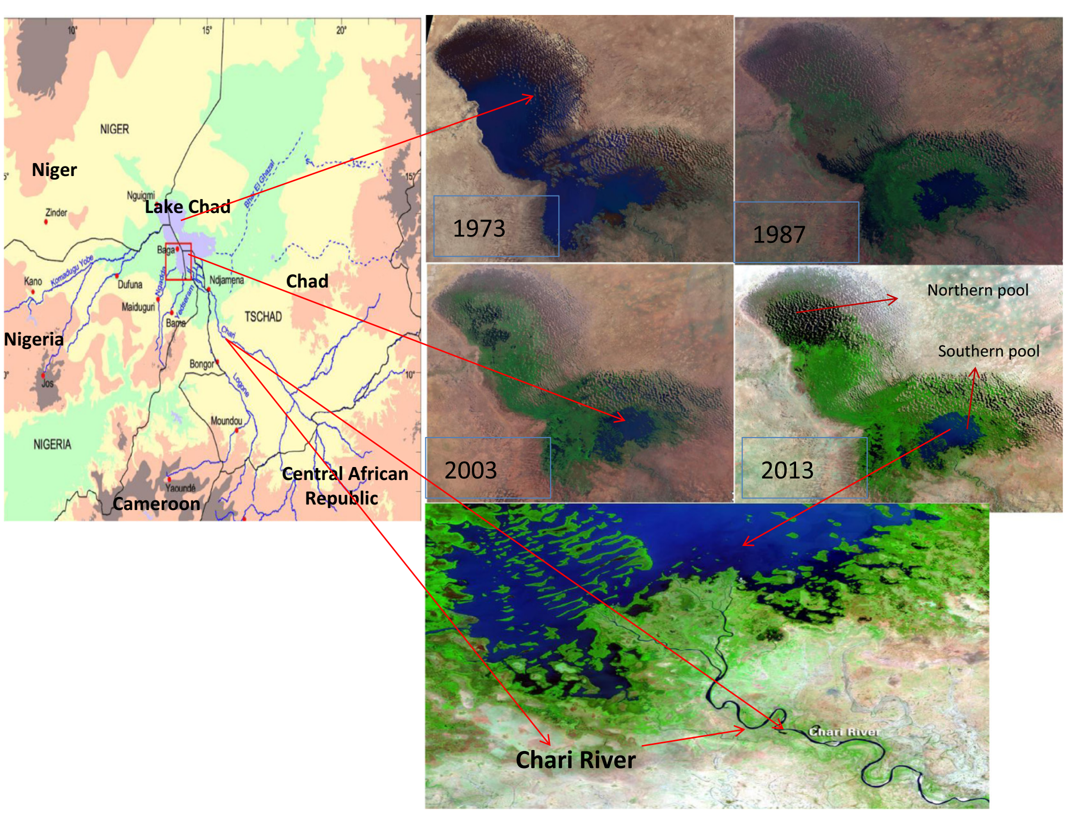


**Fig. 2.** The spatial and temporal changes in Lake Chad surface area as shown by Landsat imageries for 1973, 1987, 2003, and 2013. The Chari river, which provides about 95% of the inflow to the Lake is indicated. The blue lines on the map (left) show the river networks within the basin most of which constitute the Chari river system. The present Lake Chad show two segmented pools with the northern pool completely dried up during drought periods (right). Maps and imageries are adapted from (i) www-stud.informatik.uni-frankfurt.de/sfb268/d6/pics/misc/franke2000gr-abb1-gross.gif and (ii) United States geological surveys (http://earthshots.usgs.gov/earthshots/Lake-Chad-West-Africa). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)