Journal of Hydrology 527 (2015) 420–432

Contents lists available at ScienceDirect

Journal of Hydrology

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

Processes that control water chemistry and stable isotopic composition during the refilling of Lake Ngami in semiarid northwest Botswana

Scott D. Meier [a], Eliot A. Atekwana [a,*], Loago Molwalefhe [b], Estella A. Atekwana [a]

[a] Boone Pickens School of Geology, 105 Noble Research Center, Oklahoma State University, Stillwater, OK 74078, USA
[b] Department of Earth & Environmental Sciences, Botswana International University of Science and Technology, Private Bag 16, Palapye, Gaborone, Botswana

ARTICLE INFO

Article history:
Received 27 June 2014
Received in revised form 24 March 2015
Accepted 24 April 2015
Available online 2 May 2015
This manuscript was handled by Laurent Charlet, Editor-in-Chief, with the assistance of Philippe Negrel, Associate Editor

Keywords:
Arid environment
Evapoconcentration
Lake Ngami
Okavango Delta
Stable isotopes
Carbon cycling

SUMMARY

Lake Ngami in semiarid Botswana was dry until 2009 when it began filling with water because of regional increases in precipitation and from redirection of water to the lake from distributaries of the Okavango River. We measured the physical, chemical and stable isotopic composition of lake water collected at 25 cm below the surface along a ~18 km axial transect from the inflow river to the distal end of the lake. Our objective was to determine the processes that control water properties and to establish baseline values for future temporal and spatial comparisons. The major ionic concentrations (e.g., Cl^-, Na^+, Ca^{2+}) and the stable oxygen ($\delta^{18}O$) and hydrogen (δD) isotope ratios show three distinct regions of increasing concentrations and isotopic enrichment, respectively along the transect. The $\delta^{18}O$ vs. δD data plot along the Okavango Delta evaporation line and suggest modification of lake water by evaporation. The proportions of the major ions in the inlet water and in the lake were similar and $\log Cl^-$ vs. $\log Na^+$ suggests an evaporative enrichment of solutes. The segmentation of the major solutes and the $\delta^{18}O$ and δD into three regions along the axial transect results from differential evaporation of lake recharge from 2010, 2011 and 2012, and are thus controlled by the residence time of recharge in the lake. Unlike the major ions, the dissolved inorganic carbon (DIC) concentrations and the stable carbon isotopic ratios ($\delta^{13}C$) of DIC increase along the axial transect to about midway in the lake, and then reach steady state. The $\delta^{13}C$ of dissolved organic matter in the inlet river and lake averaged ~−25.7 ± 0.3‰ while that for particulate organic carbon decreased from ~−24‰ in the inlet river to ~−28‰ in the lake from water column productivity. Carbon cycling in Lake Ngami is controlled by evaporation which increase DIC concentrations and equilibration between carbon in DIC and atmospheric $CO_{2(g)}$. The results show the importance of evaporation and residence time in controlling the solute chemistry and the dominance of atmospheric $CO_{2(g)}$ in controlling carbon cycling during the filling stages of lakes in arid environments.

1. Introduction

Knowing the chemical and isotopic composition of surface waters in arid regions is important in understanding the functioning of aquatic ecosystems and for water quality. This is especially true in the middle Kalahari Desert of northwest Botswana where the annual flooding of the Okavango Delta is necessary for the preservation of pristine wildlife habitat of the Okavango swamps and to support the local economy through tourism (Kgathi et al., 2006). Recent variations in regional climate have caused the Okavango Delta to receive more inflow water which has resulted in the formation of new water courses and pooled in depressions to form lakes (Gaughan and Waylen, 2012; Wolski et al., 2014). The quality of the newly pooled water is of critical importance, as it will support new ecosystems and may be used for potable water supply.

One instance of the pooled surface water is Lake Ngami located at the southwest distal portion of the Okavango Delta (Fig. 1). Hydrological controls that affect filling and drying of Lake Ngami and other lakes in the region center around seasonal flooding of the Okavango Delta by discharge originating from catchments in the highlands of subtropical Angola (McCarthy and Ellery, 1998), as well as the redistribution of water to the distributaries that flow into the lakes (Shaw et al., 2003; Wolski et al., 2014). Periodic shifts in regional climate and hydrologic changes within the Okavango Delta have caused Lake Ngami to alternate between filling and drying cycles throughout its existence. However, the lake has remained mostly dry for the majority of the twentieth century (Grove, 1969; Shaw, 1985; Shaw et al., 2003). Recently, Lake

* Corresponding author. Tel.: +1 405 744 9247; fax: +1 405 744 7841.
E-mail address: eliot.atekwana@okstate.edu (E.A. Atekwana).

http://dx.doi.org/10.1016/j.jhydrol.2015.04.050
0022-1694/

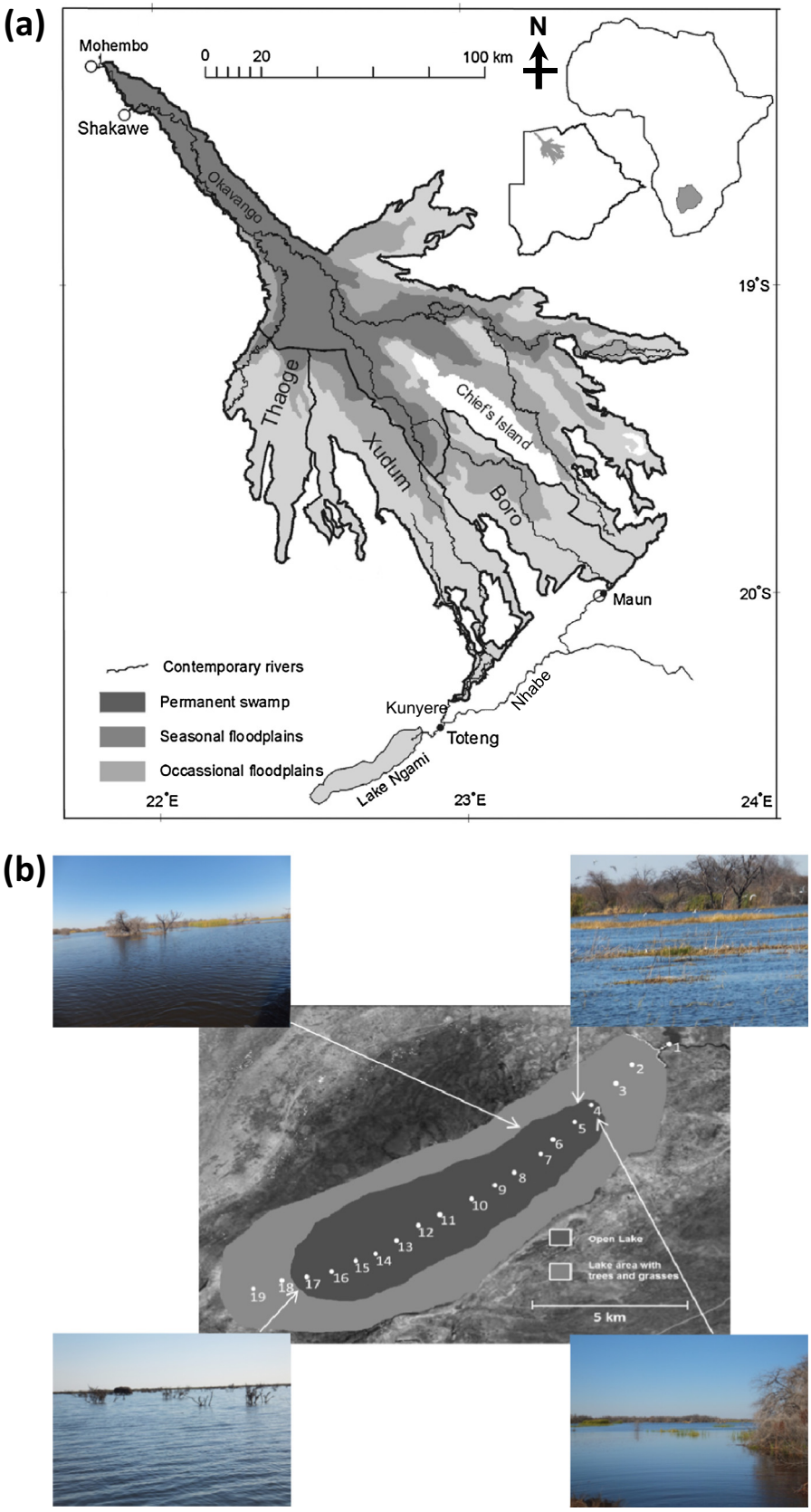

Fig. 1. (a) The Okavango Delta with distributary channels. Insert shows Africa and the locations of Botswana and the Okavango Delta (modified from Wolski and Murrary-Hudson (2006)) and (b) Lake Ngami showing the outline of drowned vegetation and stations sampled across a longitudinal transect of the lake. Photographs show the nature of vegetation conditions at the edges of the lake for select locations.