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A comparative assessment of Australia's Lower Lakes water quality under extreme drought and post-drought conditions using multivariate statistical techniques

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ABSTRACT

Drought generally results in a decline to freshwater quality, but the spatial nature of these impacts and recovery processes in large lakes systems remain poorly understood. This study applied multiple statistical methods such as cluster analysis (CA), discriminant analysis (DA), principal component analysis (PCA) and factor analysis (FA), to assess spatial and temporal variations of water quality in the Lower Lakes (Australia) during drought (April 2008–September 2010) and post-drought (October 2010–October 2013) periods. The comprehensive analysis of water quality from 22 locations and including 22 key parameters showed that Lower Lakes were eutrophic in both drought and post-drought periods with higher nutrient and algae concentrations than guideline levels for aquatic ecosystem. The Lower Lakes were identified three distinct spatial zones, i.e., (1) low eutrophication for the southeast of Lower Lakes (SE), (2) moderate eutrophication for northeast of Lower Lakes (NE), and (3) high eutrophication for northwest of Lower Lakes (NW) in the drought as well as low eutrophication for NW and high eutrophication for SE in the post-drought. DA allowed a better reduction in the dimensionality of the large dataset during post-drought than during the drought period with better results for spatial analysis rather than for temporal analysis regardless of hydrological periods. PCA/FA reflected three major factors of mineral dissolution, erosion and anthropogenic sources accounting for water constituents. Our results demonstrate the powerful utility of multivariate statistical techniques for revealing the persistent and spatially complex nature of drought-induced impacts on lake water quality and highlight that optimal utilization of water resources in the upper catchment of Lower Lakes are urgently needed for the sustainable lake ecosystems.

1. Introduction

Drought results in the deterioration of water quality in rivers and lakes as a consequence of increased salinity (Yan et al., 1996), acidification (Mosley et al., 2014a; b), temperature (van Vliet and Zwolsman, 2008) and eutrophication (Caruso, 2002; Mosley et al., 2012). Such changes to water quality result mainly from reduced flushing/outflows, increased residence time and evapoconcentration (Caruso, 2001; Flanagan et al., 2009). Although numerous studies have focused on the spatial and temporal variability of water quality (Mayer et al., 2010; Olds et al., 2011), little information is available on the comparative assessment of water quality covering both drought and post-drought periods (Li et al., 2017; Mosley, 2015). This is urgent for understanding water quality impacts of drought and thus water quality management given the

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projection of increases in frequency and intensity of hydrological droughts in the future in many parts of the world under a changing climate (van Vliet and Zwolsman, 2008), and especially in south-eastern regions of Australia (Leblanc et al., 2009; Spinoni et al., 2014).

Assessment of water quality using multivariate analysis techniques such as cluster analysis (CA) (Koklu et al., 2010; McKenna, 2003), discriminant analysis (DA) (Batayneh and Zumlot, 2012; Johnson and Wichern, 1992), principal component analysis (PCA) and factor analysis (FA) (Alexakis, 2011; Helena et al., 2000) are well established. These statistical methods are appropriate for dealing with multiple and varying parameters that when combined, contribute to overall water quality. These methods are powerful for data mining and help to improve the knowledge of water quality dynamics identifying possible factors/sources and offering a useful tool for effective management of water resources (Muangthong and Shrestha, 2015; Vega et al., 1998).

Recently, the Murray-Darling Basin (MDB), the largest river system in Australia, suffered the effects of severe drought and the lowest flows in over 100 years of records (Mosley et al., 2012). The Lower Lakes (Lakes Alexandrina and Albert), at the downstream extent of this river system, experienced increased salinity (Mosley et al., 2012), water acidification (Mosley et al., 2014a; b), eutrophication (Li et al., 2017) and even switched from sink to source of atmospheric CO_2 (Li et al., 2016) during drought. The changes in water quality were attributed to the reductions in autumn rainfall and extraction of water for agriculture, domestic supply and industry use (Li et al., 2017; Mosley et al., 2012). Previous researches reported the effects of drought on spatial and temporal variations of water quality in the Lower Lakes (Li et al., 2016, 2017; Mosley et al., 2012). However, the current knowledge of water quality variability in the Lower Lakes is limited to the analysis of data from a small number of locations (Li et al., 2016, 2017; Mosley et al., 2012, 2014a; b), and further there is no quantitatively comparative assessment of water quality in the Lower Lakes, spanning the drought and post-drought periods.

In this study, two large datasets obtained during drought (April 2008–September 2010) and post-drought (October 2010–October 2013) periods, were investigated in detail using multivariate analysis techniques to assess both the spatial and temporal variations in water quality data matrix of the Lower Lakes. Considering the changing climate and required sustainable water resources allocation, this study contributes importantly to understanding the full magnitude water quality impacts of drought and post-drought on large freshwater lakes and for informing optimal strategies for improving water management. Our specific objectives were: (1) to extract the spatial similarities among sampling sites during both drought and post-drought periods, (2) to identify water quality variables responsible for spatial and temporal variations, and (3) to identify the most important factors in determining the water quality variability and the influence of possible sources on the water quality of the Lower Lakes. We test the hypothesis that drought decreases lake water quality, while lake refill following the drought will potentially improve the water quality, and different parameters govern spatial and temporal water quality patterns across these hydrological conditions.

2. Methods

2.1. Study area

The Lower Lakes (Lakes Alexandrina and Albert) (35°25′ S, 139°07′E) are near the mouth of the Murray River and are the major water storage for the lower reaches of the vast Murray-Darling Basin (MDB) (Fig. 1). The prevailing climate is subtropical to semi-arid with a distinct seasonality of temperature and rainfall. Together the Lower Lakes cover an area of 820 km^2. Lake Alexandrina is the larger of the two and sits on the main course of the

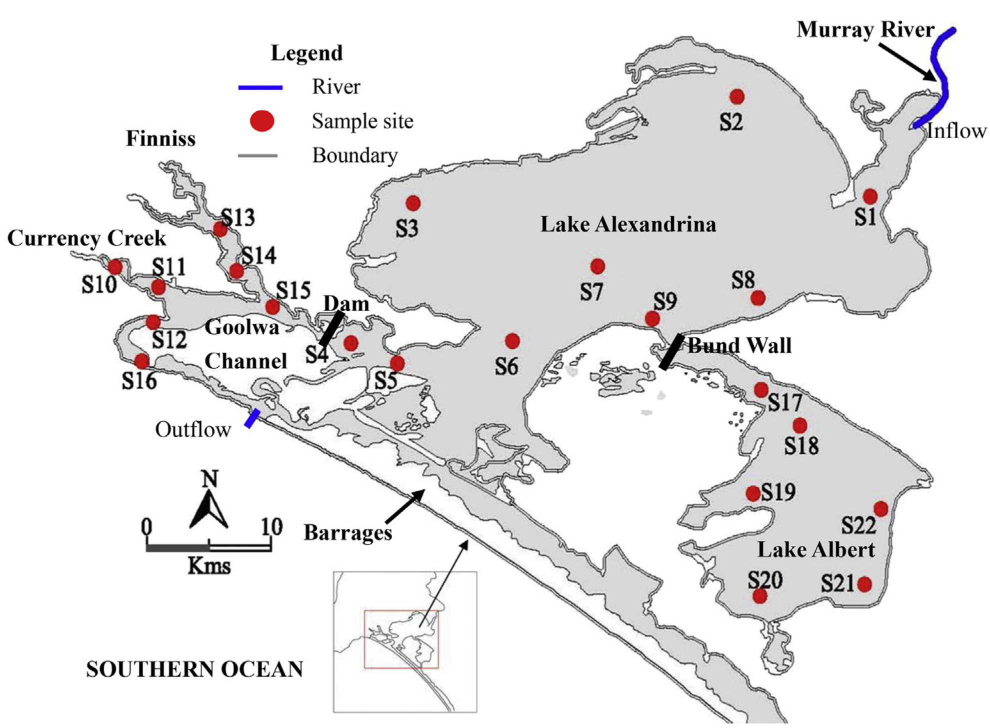

Fig. 1. Sampling sites in the Lower Lakes (Lake Alexandrina: S1 Opening, S2 Top, S3 Milang, S4 Clayton, S5 Island, S6 Point Mcleay, S7 Middle, S8 Poltalloch, S9 Narrung, S10 Currency 1, S11 Currency 2, S12 Currency 3, S13 Finniss 1, S14 Finniss 2, S15 Finniss 3, S16 Goolwa Barrage; Lake Albert: S17 Narrung, S18 Opening, S19 Campell park, S20 South west, S21 Meningie, S22 Water level recorder).