



Original Articles

Occurrence of water phosphorus at the water-sediment interface of a freshwater shallow lake: Indications of lake chemistry



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ABSTRACT

Better understanding of the occurrence of water phosphorus (P) at the water-sediment interface is vital to clarify P sources of origin in freshwater shallow lake ecosystems. This study focused on water-sediment interface systems and explored implicit indications of lake chemistry on water P based on a case study of Baiyangdian Lake, North China. 20 variables from 14 sampling sites collected for six months in two years were investigated, including sequentially extracted P fractions. Exploratory data analysis with multivariate statistical techniques and the index of P maximum solubilization potential were employed to examine interactions of water P and coexisting chemicals, and to accomplish pattern recognition of water-sediment interface systems. Results showed that nine key variables (temperature, conductivity, ammonium nitrogen, total nitrogen, sediment total P, metallic oxide bound P, organic P, aluminum and ferrum) were identified and ranked into four latent parameters (physical factors, nutrients, P species, and metals), accounting for 81% of water P variation. Accordingly, the recognized three patterns of water-sediment interface unraveled spatial partitioning for the domination of external or internal P sources. Four variables (temperature, sediment total P, metallic oxide bound P and organic P) were competent to classify patterns of water-sediment interface with 100% correct assignment of cases. Using two parameters (organic P and metallic oxide bound P), discriminant functions produced 85.7% correct assignments, indicating the importance of the two P species in explaining spatial heterogeneity of water P under oxic and alkaline circumstances. This study provides an operational zoning frame and implications for eutrophication management applicable to freshwater shallow lakes.

1. Introduction

Lake eutrophication induced by excessive phosphorus (P) is a major manifestation of water quality deterioration and ecological degradation in aquatic environments. Massive P loading in water column can promote primary productivity and reduce biodiversity, leading to serious environmental consequences and undesired ecological disasters (Søndergaard et al., 2003; Wetzel, 2001). Therefore, various management strategies and lake restoration techniques have been developed to mitigate water total P concentration below a safety threshold. Lake water P level largely depends on integration of the sources of external input and internal release (Bechmann et al., 2005). As the two pathways comparably contribute to water column, suppression of one source would not always immediately gain positive responses, since the

other one could compensate any improvement till new equilibrium established (Wetzel, 2001). Moreover, effectiveness of mitigation strategies might be confusing without knowledge on water P sources at a specific area (Blaas and Kroeze, 2016; Pu et al., 2015). Thus, to determine interacting patterns of P sources is a promising way to highlight focal points of managerial controls to be implemented.

A host of factors impose impacts on lake water P, among which external loading derived from increasing anthropogenic activities is a major cause (Bechmann et al., 2005). P from external loading could dramatically decline after controlling point and non-point source discharge, but little effectiveness was observed following agricultural management practices and buffer strips installation (May et al., 2012). It could be partly explained by selective soil erosion and fine soil particles transportation that substantially bring P materials into lake

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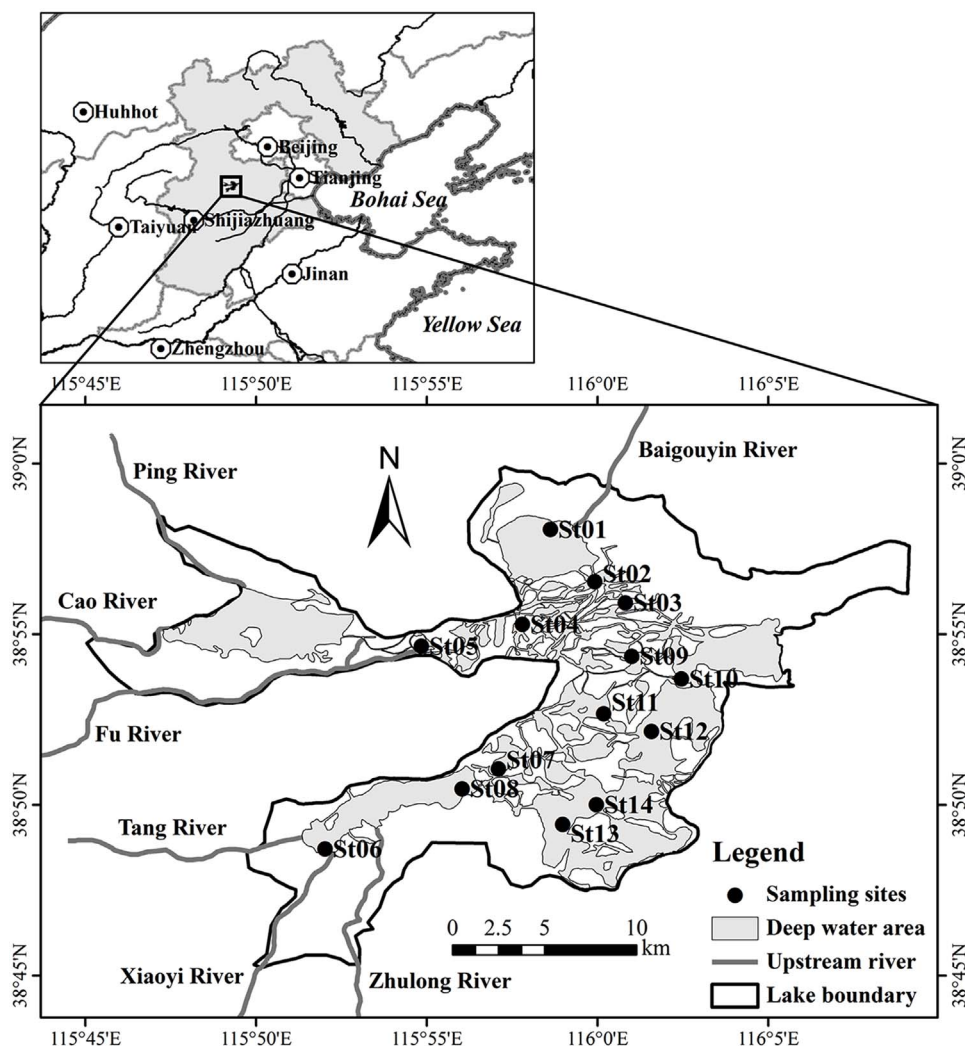


Fig. 1. Illustration of the location of the Baiyangdian Lake, China, and the major upstream rivers, indicating the deep water surface and a set of sampling sites.

ecosystems (Kerr et al., 2011). Reduction of external inputs accelerates prevalence of sediment P liberation to water column at rates which depend on physicochemical and biological parameters (Søndergaard et al., 2003). Yet, promoted P release rate from sediments is still regarded as a positive sign of lake recovery since internal P is constantly exported out of the systems, even though lake recovery period is prolonged (May et al., 2012). Lake characteristics (like average depth, fractional P retention and areal hydraulic loading) are highly associated with water P level (Brett and Benjamin, 2008). A classic model in predicting lake water P concentrations, the Vollenweider mass balance model, employed morphometric and hydraulic parameters to evaluate P burden and retention (Vollenweider, 1976). Based on this model, P concentration was demonstrated to be moderately correlated with input P concentration (Brett and Benjamin, 2008). Increase in water P concentration was also found to be accompanied with a rise of water nitrogen concentration in freshwater lakes, following a hyperbolic relationship (Guildford and Hecky, 2000). Furthermore, temperature, pH, and redox potential as well as contents of Ca, Al and Fe in sediments could influence P release and retention in sediments, regulating P level in overlying water (Christophoridis and Fytianos, 2006; Sánchez et al., 2007). However, less attention has been paid on integrated coupling implications of lake chemistry on occurrence of water P. P was one of important indicators of aquatic and terrestrial ecosystems (Aguiar et al., 2013; Castoldi et al., 2009; van Puijenbroek et al., 2014). For lake ecology, we hypothesized that water P exhibit certain associations with lake chemistry variables which might simultaneously exert appreciable repercussions on water P variation.

The operationally defined P fractions in sediments based on sequential extraction schemes, commonly referred as fractionation, contribute to water P variation and are competence in indicating potential and preference of sediment P release. Numerous studies have revealed within-lake cycling of P fractions in physical, chemical and biological processes controlling mechanisms of P liberation (Cheng et al., 2014; Søndergaard et al., 2003). Moreover, these studies provide pivotal information on contributions of internal P to water column. Nonetheless, these conclusions were drawn from net changes in amounts of P fractions regardless of mutual transformation, possibly leading to over- or underestimates. It remains unclear to what extent P fractionation reflects water P variability or whether synergistic effects of P fractions and lake chemicals override current details in P source apportionment. Particularly in shallow lakes where water is frequently mixed relative to deep lakes, intensive hydraulic dynamics and biological activities dramatically accelerate P cycling and transformation (Johnson, 2010). High ratio of sediment surface versus water column promotes water-sediment interaction, e.g. resuspension of surface sediment and bioturbation mixing (Søndergaard et al., 2003). With abrupt gradients, water-sediment interface specifically acts a transition zone and a boundary (Serrano et al., 2017). P dynamic exchange persists in overlying water (back-diffusion and deposition) and in upper sediments (solute release and burial) across the interface (Jensen and Andersen, 1992).

With the considerations mentioned above, this study aimed to investigate coupling implications of lake chemistry on occurrence of water P at water-sediment interface with special emphasis on roles of P

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