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Phosphorus fractions and phosphate sorption characteristics in relation to the sediment compositions of shallow lakes in the middle and lower reaches of Yangtze River region, China

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Abstract

Phosphorus is recognized as the most critical nutrient limiting lake productivity. The trophic status and development of lake systems are also influenced by the phosphorus content and fractions and phosphate sorption characteristics of the lake sediments. The phosphorus fractions and phosphate sorption characteristics of sediments in shallow lakes from the middle and lower reaches of Yangtze River region in China were investigated. The results show that the phosphorus contents in the sediments ranged from 217.8 to 1640 mg kg^{-1}; inorganic phosphorus (IP) was the major fraction of total phosphorus (TP); phosphorus bound to Al, Fe, Mn oxides, and hydroxides (Fe/Al–P), and calcium bound phosphorus (Ca–P) were the main fractions of IP. Phosphate sorption on the sediments mainly occurred within 2 h and then reached equilibrium in 10 h. The phosphate sorption rate was closely related to the concentration of fine particles. The phosphate sorption capacity ranged from 128.21 to 833.33 mg kg^{-1}, showing a significant correlation with the contents of Fe, Fe + Al, total organic carbon (TOC), cationic exchange capacity, total nitrogen, TP, Ca, IP, and the ratio of P/(Al + Fe), and it was higher in the sediments of eutrophic lakes than in mesotrophic lakes. Phosphate was mainly sorbed onto Fe and Al particles. The phosphate sorption efficiency ranged from 26.74 to 312.50 L kg^{-1}, and had a strong positive correlation with Fe content. For the eutrophic lake sediments, there were no significant relationships between the phosphate sorption efficiency and the selected physical and chemical parameters. But for the mesotrophic lake sediments, the phosphate sorption efficiency was found to be positively related to the contents of Al and Fe + Al.

Keywords: Phosphorus fractions; Phosphate sorption; Sediment; Middle and lower reaches of Yangtze River region; Lake

1. Introduction

The phosphorus content and fractions and phosphate sorption characteristics of the lake sediments affect the trophic status and development of the lake system [1,2]. Usually lake sediments act as a sink for phosphorus [3]. However, under certain conditions, the sediment may become a phosphorus source that can support the trophic status of the lake system [4,5]. Not all of the phosphorus fractions can be released from sediments into the overlying water and lead to lake eutrophication [1,6]. Therefore, the phosphorus behavior in lake sediments for promoting lake eutrophication can be more efficiently evaluated based on the phosphorus fractions, instead of the total phosphorus content [3]. Phosphorus fractions in lake sediments can be divided into different fractions such as labile phosphorus, reductant phosphorus, metal-bound phosphorus, occluded phosphorus, and organic phosphorus using various chemical extractants [7–9]. According to the SMT protocol [10], the phosphorus fractions

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can be characterized as inorganic phosphorus (IP), phosphorus bound to Al, Fe, and Mn oxides and hydroxides (Fe/Al–P), calcium-associated phosphorus (Ca–P), organic phosphorus (OP), and total phosphorus (TP).

The phosphate sorption at the sediment–water interface of lakes is an important process that affects the phosphorus transport, the bioavailability, and the concentrations in the overlying water, so this process had been widely investigated [11,12]. When phosphorus was sorbed onto the particle surface, the equilibrium process was usually described by the Langmuir sorption isotherm [13]. The phosphate sorption capacity of lake sediments was related to their compositions [14]. Although the phosphate sorption mechanism is not well understood, a large phosphate sorption capacity was reported to be related to the contents of Fe/Al (hydr)oxides in oxic estuarine and oceanic sediments [15–18]. One of the more important factors affecting the phosphorus exchange between the lake sediment and its overlying water was the particle-size distribution in the sediments [19]. Thus, sediments with different characteristics may have different phosphate sorption characteristics [20].

The phosphate sorption of the sediments from coastal estuaries, oceans, and deep lakes has been extensively studied over the past 30 years [21]. However, studies on the sediments from shallow lakes were not often reported, and little is known about the phosphorus fractions of the sediments from those Chinese shallow lakes.

The middle and lower reaches of the Yangtze River region are central areas of freshwater shallow lakes in China. Most of the lakes in this region have been under mesotrophic or eutrophic conditions, and the eutrophication is especially common [22]. The source of the nutrient enrichment in the lake sediment is the nutrient loaded from the watershed, and the high primary production of the lake is the consequence of the nutrient external loading and in several cases also from the flux of the nutrient released from sediments [23]. The aims of this study were to investigate the characteristics of the phosphorus fractions in the surface sediments of lakes from the middle and lower reaches of the Yangtze River region, to calculate the phosphate sorption capacity, to describe the kinetics and isotherms of the phosphate sorption on the sediments, and also to analyze the relationship between the phosphate sorption characteristics and the sediment compositions.

2. Materials and methods

2.1. Study area

The studied lakes are located in the middle and lower reaches of Yangtze River region (Fig. 1). There are 651 lakes with areas are larger than 1 km^2 and there are 18 lakes with areas larger than 100 km^2 in this region [24]. Most of the lakes are shallow with large surface areas. The total lake surface area in this region is more than 21,000 km^2, accounting for 25% of all water surface area of lakes in China. Poyang Lake, Dongting Lake, and Taihu Lake have surface areas of 3960, 2470, and 2440 km^2, respectively, and they are the largest surface area lakes in China [25]. Most of the lakes are under mesotrophic or eutrophic conditions due to agrochemical and chemical fertilizer overusage, discharge of the municipal sewage, large-scale cultivation, and high-density population in the watershed. Those lakes are the main eutrophic region in China [22], and are a restriction factor that affects the economic development of this region [26]. Taihu Lake is eutrophic [27], Yue Lake and Xuanwu Lake are urban lakes and have been hypereutrophic [28], Chao Lake,

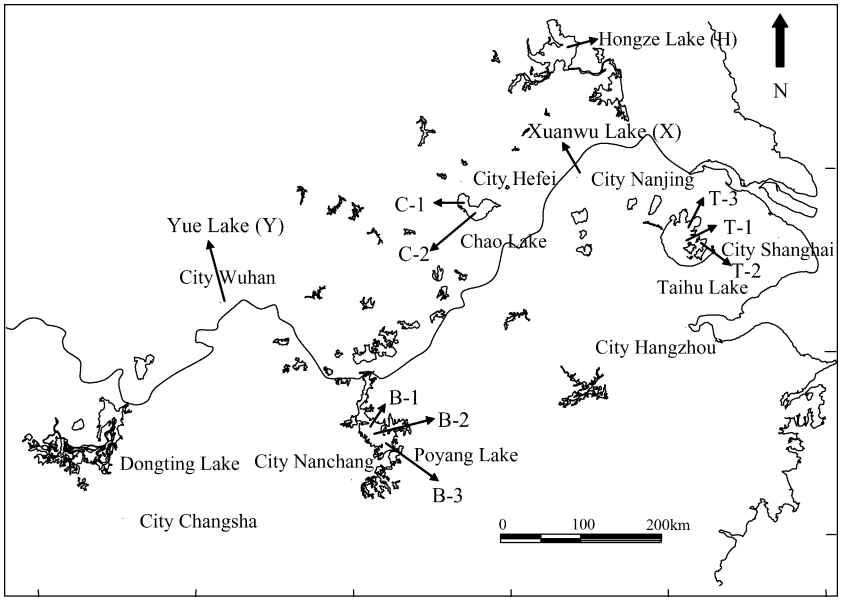

Fig. 1. The geographic location of the sampling sites.