Phosphorus fractionation in lake sediments – Lakes Volvi and Koronia, N. Greece

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Abstract

Sediments from two lakes, the meso-to-eutrophic Volvi and the hypertrophic Koronia, located in N. Greece were examined on the basis of P-fractionation. In both lakes, the rank order of P-fractions was HCl-P > NaOH-P > BD-P > NH₄Cl-P. The loosely sorbed phosphorus (NH₄Cl-P) represented <1% of the sedimentary inorganic phosphorus, while the reductant phosphorus (BD-P) ranged 5–6%. The calcium bound phosphorus (HCl-P) showed considerable contribution (59–74%) to the sedimentary inorganic P-loads. The metal oxide bound phosphorus (NaOH–P) was higher in the hypertrophic (30–35%) than in the meso-to-eutrophic system (19–28%). Fine-sized sediments exhibited significantly higher concentrations of HCl-P in Volvi and NH₄Cl-P in Koronia. Sampling month had significant effect in variance of most P-fractions and other sediment features in both lakes. Use was also made of multivariate statistics to identify the factors which influence the sedimentary phosphorus. NaOH–P was the most reactive fraction in Lake Volvi. Iron compounds and organic matter seem to play a significant role in regulating this labile P-budget. NH₄Cl–P was the more reactive fraction in Lake Koronia which was influenced by sedimentation of P-absorbed on clay/silt fine particles. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Grain size; Lakes; PCA; Phosphorus; P-fractions; Sediment; Trophic status

1. Introduction

Phosphorus has been recognized as the most critical nutrient limiting lake productivity. The main sources of phosphorus in lakes are external point and non-point sources such as rainfall, runoff, soil leaching, industrial and municipal effluents. Moreover, there are also internal sources from the system itself such as aquatic plants, algal and sediments.

The trophic status of the lakes is usually dependent on the P-concentration in the water. In addition, the trophic status and the trophic development of the system is also influenced by the phosphorus content in lake sediments. Usually lake sediments act as a sink of phosphorus. However, under certain environmental conditions, the sediments may become a possible phosphorus source that will support the trophic status of the lake even after a reduction of external loading (Ramm and Scheps, 1997; Zhou et al., 2001). This internal P-loading may delay the recovery of the lakes, once the external P-sources are reduced, and must be evaluated in lake restoration programmes. The phosphorus content in sediments depends on the sediment composition, the sedimentation rate, the physicochemical conditions and the extent of diagenetic processes (Gonsiorczyk et al., 1998). Total concentrations of phosphorus in sediments cannot predict the potential ecological danger. The fraction of available phosphorus is an important parameter for predicting future internal P-loading. The factors governing P release from sediments comprise redox reactions, adsorption, mineral phase solubility.

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<table>
<thead>
<tr>
<th>Variable</th>
<th>Lake Volvi</th>
<th>Lake Koronia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F_1$</td>
<td>$F_2$</td>
</tr>
<tr>
<td>NH$_4$Cl-P</td>
<td>0.511</td>
<td>0.765</td>
</tr>
<tr>
<td>BD-P</td>
<td></td>
<td>0.934</td>
</tr>
<tr>
<td>NaOH-P</td>
<td>0.931</td>
<td></td>
</tr>
<tr>
<td>HCl-P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand (%)</td>
<td>-0.472</td>
<td></td>
</tr>
<tr>
<td>LOI (%)</td>
<td>0.859</td>
<td></td>
</tr>
<tr>
<td>CaCO$_3$ (%)</td>
<td></td>
<td>0.831</td>
</tr>
<tr>
<td>Ca</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al$^3+$</td>
<td>0.526</td>
<td></td>
</tr>
<tr>
<td>Fe$^{III}$</td>
<td>0.968</td>
<td></td>
</tr>
<tr>
<td>Mn$^{II}$</td>
<td>0.658</td>
<td></td>
</tr>
<tr>
<td>Variance (%)</td>
<td>47.2</td>
<td>18.4</td>
</tr>
</tbody>
</table>

*Loadings higher than 0.400 are only given.

important role of iron compounds (more important than aluminum) and organic matter in regulating this mobile P-budget of the lake (Maine et al., 1996). It is also indicates that this P-form can be considered the most reactive one in this system. The second factor accounting for 18.4% of the variance was correlated with Ca$_{total}$, CaCO$_3$, Mg$_{total}$, and NH$_4$Cl-P. This factor suggests that carbonates or manganese may control the presence of loosely bound P and probably represents the autochthonous precipitation of P (Sallade and Sims, 1997; Gonsiorczyk et al., 1998). The third factor which is strongly correlated with BD-P, NH$_4$Cl-P and Mg$_{total}$, shows that redox conditions and the presence of Mg, both dependent on algal productivity, could influence the mobile pool of the lake (Gonsiorczyk et al., 1998). Lastly, the fourth factor was positively correlated with HCl-P and sand content of the sediment whereas negatively with Al$^3+$. This factor could represent the allochthonous origin of the sedimentary phosphorus, probably due to erosion processes.

Three factors accounting for 84.7% of total variance were identified in lake Koronia (Table 4). The first factor, accounting for 57.5% of the variance, was positively correlated with NH$_4$Cl-P, LOI, CaCO$_3$ and total concentrations of Mg, Al, Fe, Mn while negatively correlated with sand content and Ca$_{total}$. This factor could be interpreted as representing the processes influencing the loosely bound P that seems to be the most reactive fraction in this system. These processes might include settlement of planktonic diatoms and deposition of finely sized particles where P is associated with carbonates, organic matter, ferromanganese oxides (Pizarro et al., 1992; Sohrin et al., 1996; Johnson, 1997; Gibson et al., 2001; Pettersson, 2001). The second factor, accounting for 17% of the variance, was positively correlated with NaOH-P and negatively with BD-P and NH$_4$Cl-P thus representing the interrelationships among the algal available phosphorus fractions. Mineralization of organic matter could be one possible route of mobilized P from NaOH-P to the other P-fractions (Gonsiorczyk et al., 1998). The third factor, accounting for 10.2% of the variance, was primarily correlated with HCl-P and negatively with BD-P showing that the terrigenous forms P extracted by strong acids might contain P forms that could be possible source of reductant P, probably due to bacterial activity that could solubilize P-compounds (Maine et al., 1992; Sallade and Sims, 1997).

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