Modeling the environmental fate of Lead in Lake Biwa-Yodo River basin of Japan

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Abstract

Various chemical substances have been emitted to the environment through anthropogenic activities for the past several decades. Risk assessment of hazardous chemical substances on human health and ecosystems requires their concentrations in the environment. Multimedia fate models are useful tools to estimate environmental concentrations of persistent substances, such as persistent organic pollutants (POPs) and heavy metals. In addition, the models can interpret the correlation between emissions and environmental concentrations of chemical substances.

This study focused on the environmental fate of lead in Lake Biwa-Yodo River basin, which is the basin with the second largest population (11 million) in Japan. A large amount of Lead had been emitted in the 20th century and adverse effect of environmental lead on human health have been concerned. Two types of multimedia fate models were developed to simulate behavior of environmental lead: the first was one-box model and the second was distributed model. The models are based on mass balance equations in four environmental media: the atmosphere with two layers, the soil, the water body and the sediment. The mass balance of lead is represented by the summation of mass transfer flux at equilibrium, emission flux, advection flux, and deposition flux or sedimentation flux. In addition, dissolution rate and exchange equilibrium are taken into consideration. The one-box model assumes homogeneous mixing in the environmental media in Lake Biwa-Yodo River basin. The distributed model represents the basin by model grids with a horizontal resolution of 1 km × 1 km. Lead emissions in the basin were estimated for the period from 1957 to 2007 to simulate temporal accumulation of environmental lead. Emissions from industrial sectors and sewage treatment plants were derived from the Pollutant Release and Transfer Register (PRTR) database in Japan. Emissions from waste incinerations, exhausts of vehicles using leaded gasoline and paint applications were estimated using other statistics.

The model performance was evaluated with measured concentrations in Osaka and Kyoto Prefecture in 2007. The one-box model underestimated lead concentration in the atmosphere, but well captured concentrations in the soil, the water body and the sediment. The calculated concentration in the atmosphere showed rapid decreases in 1970s because of the regulation of leaded gasoline and in 1990s because of the improvement in exhaust gas treatment of incineration plants. The calculated concentrations in the soil and the sediment increased until 1970s, and were almost stable in the remaining period.

The distributed model was driven with spatially allocated emission data and results of meteorological and hydrological model simulations. While the temporal variation pattern of spatial mean lead concentration in the atmosphere calculated by the distributed model was quite similar to that calculated by the one-box model, concentrations calculated by the distributed model were spatially variable and higher in Osaka and Kyoto Prefecture. The spatial mean concentrations in the soil, the water body and the sediment calculated by the distributed model have increased throughout the simulation period. The differences of temporal variations between the one-box and the distributed models are mainly attributed to the differences in spatial distributions of the environmental media and precipitation.