QUANTIFYING PRESENT AND FUTURE MERCURY DEPOSITION AND BIOACCUMULATION TO RICE IN CHINA

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Introduction

Monomethylmercury (MMHg) is a toxic and bioaccumulative organometallic compound that poses serious health risks to humans. Previous studies on MMHg exposure to humans mainly addressed consumption of coastal and marine fisheries products. Recent measurements of MMHg levels in rice grains in China show elevated levels sufficient to pose human health impacts (Feng et al., 2008; Li et al., 2010; Zhang et al., 2010). China is currently the largest producer and consumer of rice, and the largest source of mercury (Hg) pollution in the world (Pacyna et al., 2010). Unfortunately, relatively little is known about the sources and biogeochemical processes governing MMHg transformation and bioaccumulation to rice grains. We use a modeling approach to 1) simulate the dominant sources and biogeochemical processes by which MMHg contaminates rice, 2) identify critical locations in China where the risk of MMHg exposure via rice ingestion is high, and 3) project future changes in rice MMHg levels under the implementation of the global Hg treaty, the Minamata Convention on Mercury.

Methods

China rice paddy area and production information are derived from Liu et al. (2013), which has been published previously and verified against Landsat TM satellite data. These data are used to map the rice paddy area and production on a provincial level (total of 31 provinces). We use GEOS-Chem, a global atmospheric-chemistry-transport model for Hg, to simulate present (year 2010-2012) and future (year 2050) anthropogenic Hg emissions and deposition to rice paddies in China. GEOS-Chem provides gridded simulation of three atmospheric Hg species: Hg^0, Hg^{2+}, and Hg_p, and uses present day meteorology from the NASA Goddard Earth Observing System. We use present and future emissions and deposition estimates from Giang et al. (2015), who implemented Minamata Convention-specific technology scenarios to Chinese coal-fired power plants (no additional control, Minamata-Flexible, and Minamata-Strict scenarios). Box model simulations consisting of four reservoirs (flooded water, topsoil, subsoil, rice) and relevant biogeochemical rate constants reflecting Hg cycling in rice paddies are constructed to simulate transformation, and bioaccumulation of MMHg to rice grains for the present day and future. Four types of box model simulation scenarios are constructed based on the atmospheric Hg source input, crop rotation cycle, and geographic location of rice paddies in China.

Results

Model simulations of the present day atmospheric Hg deposition show that the regions of high rice areas and large rice production are co-located with regions of high Hg deposition in China. The critical locations where the risk of MMHg exposure via rice consumption are prevalent in the central part of China (in the provinces of Henan, Chongqing, Hunan, Jiangxi, and Hubei), where Hg deposition is driven by proximity to large industrial Hg pollution sources and large annual precipitation rate (~1100 mm/year) that can scavenge atmospheric Hg to the biosphere. Model simulations of future atmospheric Hg deposition under three scenarios show that while overall, the regions of high atmospheric Hg deposition do not change in the future, the magnitude of deposition can decrease as much as 59% (Hainan) under the implementation of the Minamata Convention on Mercury. Preliminary box model simulations show that recently deposited atmospheric Hg and resultant biotic methylation in flooded rice paddies are the dominant source and biogeochemical process governing MMHg production and bioaccumulation to rice grains in ~90% of rice-growing provinces of China. We show that future changes in atmospheric Hg deposition under the Minamata Convention can affect MMHg exposure originating from rice ingestion in China.

Conclusion

This study demonstrates that MMHg bioaccumulation in rice resulting from anthropogenic emissions is an important source of human exposure and identifies regional hot spots where this exposure is most acute. Future technology and policy scenarios resulting in upstream removal of anthropogenic Hg are expected to change the extent of Hg deposition and MMHg exposure to Chinese rice consumers. We further estimate the potential health and economic impacts associated with these scenarios.

References

Feng, X., Li, P., Qiu, G., Wang, S., Li, G., Shang, L., … Fu, X. (2008). Human exposure to methylmercury through rice intake in mercury mining areas, Guizhou province, China. *Environ. Sci. Technol.*, *42*, 326–332.

Giang, A., Stokes, L. C., Streets, D. G., Corbitt, E. S., Selin, N. E. (2015). Impacts of the Minamata Convention on mercury emissions and global deposition from coal-fired power generation in Asia. *Environ. Sci. Technol.*, *49*, 5326-5335.

Li, P., Feng, X., Qiu, G. (2010). Methylmercury exposure and health effects from rice and fish consumption: A review. *Int. J. Environ. Res. Public Health*, *7*, 2666–2691.

Liu, Z., Li, Z., Tang, P., Li, Z., Wu, W., Yang, P., … Tang, H. (2013). Chang analysis of rice area and production in China during the past three decades. *J. Geogr. Sci.*, *23*, 105-1018.

Pacyna, E. G., Pacyna, J. M., Sundseth, K., Munthe, J., Kindbom, K., Wilson, S., … Maxson, P. (2010). Global emission of mercury to the atmosphere from anthropogenic sources in 2005 and projections to 2020. *Atmos. Environ.*, *44*, 2487–2499.

Zhang, H., Feng, X., Larssen, T., Qiu, G., Vogt, R. D. (2010). In inland China, rice, rather than fish, is the major pathway for methylmercury exposure. *Environ. Health Persp.*, *118*, 1183–1188.