DISTRIBUTION OF MERCURY AND LEAD BETWEEN SEDIMENT AND WATER IN RIVERS IN THE UNITED STATES

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ABSTRACT

A high level of metal in an aquatic ecosystem, such as river, can jeopardize the livelihood of the organisms in the ecosystem. On one hand, some type of metals are needed for metabolic processes, but a number of metals are toxic that when they are being accumulated to an abnormal level in the human body, it can be fatal. As bioavailability of a certain kind of metal is also controlled by its concentration, the distribution of metal between water and sediment in an aquatic environment also has an impact of its bioavailability and exposure to organism. A study on how metals are being distributed between water and sediment will give a better understanding about the fate of metals in the natural environment. In this study, the data is collected from various research on the concentration of mercury and lead in the river. Most of the paper report the concentration of metal in the sediment in the unit of ng/g (mercury) or µg/g (lead). However, considering that the concentration of the metal in water is mostly reported in the unit of ng/L (mercury) or µg/L (lead), metal concentrations in the sediment are converted into ng/kg (mercury) and µg/kg (lead). Assuming that the density of water is 1 g/mL, this conversion is expected to give a better rationalization in comparing metal concentration between those two different phases. The ratio of metal in water to its concentration in sediment is compared between lead and sediment, lead has a higher ratio compared to mercury. This is because dissolution of lead in water is also facilitated by suspended particle materials in the water. The content of both lead and mercury in river also comes from atmospheric deposition. Historically, lead has been widely used as one of the additives in gasoline. Thus, there is a correlation between the level of lead found in a river with the usage of gasoline.

Keywords: *metals, distribution, concentration, lead, mercury*

INTRODUCTION

a. Background

Metal pollution has been one of the major concern related to the quality of the environment. Naturally, metals already exist in the environment, mostly can be found as part of minerals. However, anthropogenic activities have made the metals being more exposed to open environment (Duruibe et al, 2007). In many cases, because of this exposure, the amount of metals found in rivers exceed its natural limit. A high level of metal in an aquatic ecosystem, such as river, can jeopardize the livelihood of the organisms in the ecosystem. On one hand, some type of metals are needed for metabolic processes, but a number of metals are toxic that when they are being accumulated to an abnormal level in the human body, it can be fatal.

A river as an aquatic ecosystem is a complex system. A river can be considered as a system comprises of some phases, i.e. the water phase, sediment, and the organism in the river (Eggleton, 2004). Metals can be found both in the sediment and in the water. Whether a certain kind of metal will be dissolved in water or precipitated and bound to the sediment is determined by a number of factors (Eggleton, 2004). In what phase the metal being present, either it is dissolved in water or in the sediment is an important thing to consider. This is because it will determine the bioavailability of the metal to the organism (Goyer, 1997).

The likelihood of exposure to these toxic metals is determined by a number of factors, and one of the most important factors is the speciation of the metals. As explained by Goyer, the speciation of metal when it enters the human body determines how the metal will interact with chemical compounds during metabolism.

b. Statement of Importance

It is important to understand the distribution of a metal in river, whether they are being dissolved in water phase, or precipitated in the sediment. As bioavailability of a certain kind of metal is also controlled by its concentration, the distribution of metal between water and sediment in an aquatic environment also has an impact of its bioavailability and exposure to organism. A study on how metals are being distributed between water and sediment will give a better understanding about the fate of metals in the natural environment.

c. Research Questions

This paper will focus on two different metals, i.e. mercury and lead. Both of the metals are toxic metals, due to the effects that may occur when organisms are being exposed to them. There are two main questions that this paper will analyze:

1. How is the distribution of lead and mercury between sediment and water in rivers in the USA?
2. What are the factors that may affect the pattern of the metal distribution between those two phases?

APPROACH AND METHODS

a. Summary of Previous Works

There has been a number of research that investigates the factors affecting the speciation and distribution of metals between water and sediment. In general, the factors affecting metal in an aquatic environment can be categorized into anthropogenic factors and non-anthropogenic factors. The picture shown in Figure 1 shows how a metal can be distributed into three different phases when it is present in an aquatic environment.

One of the most important factors about metal distribution between water and sediment is the property of the metal itself. Different type of metal being present in the same area might have different pattern of distribution, due to their different properties. Some of the metals will tend to form more stable complexes with H2O as their ligands rather than complexes that they can form with these sediment. Hence, this kinds of metal will tend to dissolve in water rather than precipitate on the sediment (Kyle et al, 2012). Other types of metals have stronger tendency to be bound to the sediment. Then again, which fraction of the sediment the metals will be bound to, either to the organic fractions or to the mineral fractions of the sediment still depends on the properties of the metal (Prica et al, 2010). Chromium, for example, has a greater tendency to be adsorbed onto the organic fraction of sediment while on the other hand, cadmium is often found in the mineral fraction of the sediment.

Besser et al (2008) have conducted a research on the metal bioavailability in sediments from Lake Roosevelt, Columbia River, Washington. The result of their research indicates that most of the metals on the sediment are mostly associated with iron and manganese oxides. However, according to Garbarino et al (1995), mercury shows a tendency to form compound with sulfides, and with organic constituents in the sediment. Another interesting characteristic is shown by lead, as its dissolution in water is mostly dominated by its tendency to be sorbed onto the suspended particulate matters (SPM) in the water (Sherrel & Ross, 1999).

As an important property of water, acidity in a certain area, which is reflected in pH value, also has a significant impact in determining the fate of metals in an aquatic environment (Kyle et al, 2011, Seidel; 2011; Ugwu et al, 2012). In an acidic environment where the pH is relatively low, toxic metals tend to be much more soluble. In this kind of situation, more metals can be found in the water instead of on the sediment. In a more alkaline condition, metals tend to precipitate. Based on their observation, Sherrel and Ross (1999) claimed that there is an inverse relationship between pH and the concentration of dissolved metals in the streams where they did their research, and lead shows a stronger tendency to precipitate on higher pH compared to Al, Cd, Cu and Zn. A higher concentration of mercury in the water is also found on lower pH, as reported by Journey et al (2012).

One of the reasons why metals precipitate is the formation of their alkaline salt. Besides that, acidity also encourages reduction-oxidation reactions that may change the speciation of metals (Seidel, 2002).

Sediment, as the site where metals will be bound when they are precipitate, also affects the distribution of metal between sediment and water. One of the sediment properties that determines how metals will be bound is the composition of the sediment. While some types of metals tend to have a stronger interaction with the organic fraction, other types of metal have a stronger tendency to interact with the mineral fractions of the sediment (Prica et al, 2012). Armstrong et al (2005) argue that the portions of metals bound to the mineral fraction of the sediment show a consistent pattern if it is being normalized to either aluminum or iron content in the sediment.

Besides the composition, the morphological structure of the sediment also plays a role in determining the amount of metal that it can hold. As described by Bentivegna et al (2004), sediment that has a high surface to volume ratio is able to bind more metal compared to sediment that occurs as larger structure. It is interesting to note that, to what fraction of the sediment is bound to also affect the bioavailability of the metal. As explained by Nordstrom (2011), the organic fraction tends to be leached easier through biogeochemical processes. Thus, according to Velinmirovic et al (2011), metals bound to this unstable fraction of sediment are often more bioavailable compared to those being bound to the mineral fraction.

River is a dynamic system, and often exhibits seasonal variability in its content of metals. In regards with this seasonal variability, the concentration of metal is mostly regulated by hydrological flow pat (Bradley et al, 2011; Sherrel & Ross, 1999). In certain areas, snowmelt can also be responsible driving force of metal mobilization. Hydrological flow also one of the explanation on the elevating concentration of mercury in the sediment downstream, compared to the sediment upstream (Chalmers et al, 2011).

b. Approach and Methods of This Study

In this study, the data is collected from various research on the concentration of mercury and lead in the river. The papers which data is used in this paper are the papers that report the metal concentration in both water and sediment. Some of the data are adjusted so all the data plotted have consistent units of concentration. Most of the paper report the concentration of metal in the sediment in the unit of ng/g (mercury) or µg/g (lead). However, considering that the concentration of the metal in water is mostly reported in the unit of ng/L (mercury) or µg/L (lead), metal concentrations in the sediment are converted into ng/kg (mercury) and µg/kg (lead). Assuming that the density of water is 1 g/mL, this conversion is expected to give a better rationalization in comparing metal concentration between those two different phases.

Concentration of mercury and lead in the sites being investigated in the report are tabulated in Table 1 (for mercury) and Table 2 (for lead).

To have a better visualization on comparing the data, metal concentration in sediment and in water is presented as a bar graphic, presented in Figure 2 and 3 (for mercury) and Figure 4 and 5 (for lead). It has to be noted that for a better display of the graph, the concentration of mercury found in the Red Devil Creek is not shown on Figure 2 and 3, due to an exceptionally high level of mercury found on that site. To compare the ratio of metal in water and sediment, the data are presented in stacked bar graphic shown in Figure 6 (for Mercury) and Figure 7 (for Lead).

ANALYSIS AND DISCUSSION

Based on the Table 1 and Figure 2, it is clearly apparent that for mercury found in the sediment is much higher in than the dissolved concentration ion water. It indicates that mercury have a stronger tendency to be accumulated in the sediment instead of being dissolved in water by forming stabile complexes in water. The retention of mercury in the sediment is very likely because of the strong affinity of mercury to be bounded on the organic fraction of the sediment. This is in line with the argument from Schelker et al (2011), the mobilization of mercury is highly dependent on the organic fraction of the sediment. The importance of mercury association with organic matters in the river is also highlighted by Garbarino, et al (1995) as a characteristic about mercury found in river. An interesting finding is the level of mercury which is exceptionally high in the Red Devil Creek, Alaska. The level of mercury found in the sediment and water are much higher, even higher than the average mercury found in the sediment and water of mined basin in the USA (Scudder et al, 2009). This is due to the sampling site which is located near an abandoned mining site. This fact comes in accordance with what has been reported by Alpers et al (2005), that mercury had often been used in historical gold mining, and thus, often found in a large quantity in abandoned mining sites.

Table 2, Figure 3 and 4 shows the concentration of lead found in the water and sediment. This metal too, like mercury, found in a bigger quantity in the sediment instead of in water. This is in line with the findings from Sherrell and Ross (1999) that lead tends to show more retention on the sediment. Compared to mercury, lead has more mechanism to be accumulated in the sediment. As stated by Sherrel and Ross (1999), the precipitation of lead as the pH of the system gets higher is more apparent for lead compared to other metals. There is no consistent pattern of the relationship between organic matter and lead in the sediment (Jara-marini et al, 2013). According to Garbarino et al (1995), the amount of lead associated to organic fraction of the sediment is usually less than 10%. In line with this, most of lead in the sediment are commonly found in the inorganic fraction (Garbarino et al, 1995), and with the manganese and iron oxide (Besser et al, 2008).

If the ratio of metal in water to its concentration in sediment is compared between lead and sediment, lead has a higher ratio compared to mercury. This is because dissolution of lead in water is also facilitated by suspended particle materials in the water (Sherrel & Ross, 1999).

Even when the concentration of lead and mercury are expressed in the same unit (microgram), the concentration of lead either in sediment or in water is always higher than concentration of mercury. This is not solely because lead naturally has higher abundance than mercury. The content of both lead and mercury in river also comes from atmospheric deposition. Historically, lead has been widely used as one of the additives in gasoline. Thus, as suggested by Alexander & Smith (1988), there is a correlation between the level of lead found in a river with the usage of gasoline.

CONCLUSION

Based on the above description, there are a number of conclusion that can be inferred:

1. In a river ecosystem, metal like lead and mercury will be distributed between the water and sediment.
2. More lead will be found in the sediment instead of in the water, and it will mostly associated with the inorganic fraction of the sediment. Increasing pH of the water will also increase the amount of lead being precipitated in the sediment
3. Mercury tends to accumulate more in the sediment instead of being dissolved in water. This is due to its affinity to interact with the organic fraction of the sediment.
4. Compared to mercury, lead has a higher solubility, because its dissolution is facilitated with its sorption to suspended particle materials in water.

LIST OF REFERENCES

Alexander, R.B.; Smith, R.A.; Trends in lead concentrations in major U.S. Rivers and their relation to historical changes in gasoline-lead consumption. Water Resources Bulletin. 1988, 24(3), 557-569.

Alpers, C.N.; Hunerlach, M.P.; May J.T.;. Hothem, R.L. Mercury Contamination from Historical Gold Mining in California. U.S. Geological Survey, Fact Sheet 2005-3014 Version 1.1, October 2005.

Andrews, W.J.; Becker, M.F.; Mashburn, S.L.; Smith, S.J.; Selected Metals in Sediments and Streams in the Oklahoma Part of the Tri-State Mining District, 2000–2006. Scientific Investigations Report 2009–5032 for U.S. Geological Survey, Reston, Virginia, 2009.

Armstrong, T.N.; Iannuzzi, T.J; Thelen, J.B; Ludwig, D.F; Firstenberg, C.E. Characterization of chemical contamination in shallow-water estuarine *habitats of an industrialized river. Part 1: Organic compounds. Soil & Sediment Contamination. 2005, 14(1), 13-33.*

Batley, G.; Birch, G.; Elder, J.F.; Fearon, R.; harle, K. Metal Contaminants. http://www.ozcoasts.gov.au/indicators/metal_contaminants.jsp *(Accessed April 1, 2014).*

Bentivegna, C.S.; Alfano, J.; Bugel, S.M.; Czechowicz, K. Influence of Sediment Characteristics on Heavy Metal Toxicity in an Urban Marsh. Urban Habitats, 2004. 2(1), 91-111

Besser, J.M; Brumbaugh, W.G; Ivey, C.D; Ingersoll, C.G; Moran, P.W. Biological and chemical characterization of metal bioavailability in sediments from Lake Roosevelt, Columbia River, Washington, USA. Archives Of Environmental Contamination And Toxicology. 2008, 54(4), 557-570.

Bradley, P.M.; Burns, D.A.; Riva-Murray, K; Brigham, M.E.; Button, D.T.; Chasar, LC; Marvin-DiPasquale, M; Lowery, M.A. ; Journey, C.A. Spatial and Seasonal Variability of Dissolved Methylmercury in Two Stream Basins in the Eastern United States. Environmental Science & Technology, 2011, 45(6), 2048-2055.

Chalmers, A.T.; Marvin-DiPasquale, M.C., Degnan, J.R., Coles, J.F., Agee, J.L.; Luce, D. Characterization of mercury contamination in the Androscoggin River, Coos County, New Hampshire. U.S. Geological Survey Open-File Report 2013–1076, 2013.

Domagalski, J. Mercury and methylmercury in water and sediment of the Sacramento River Basin, California. Applied Geochemistry. 2001, 16(15), 1677-1691.

Duruibe, J.O., Ogwuegbu, M.O.C., Egwurugwu, J. N. Heavy metal pollution and human biotoxic effects. International Journal of Physical Sciences. 2007, 2 (5), 112-118.

Eggleton, J.; Thomas, K.V. A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. Environment International. 2004, 30(7), 973-980

Garbarino, J.R.; Hayes, H.C.; Roth, D.A.; Antweiler, R.C.; Brinton, T.I.; Taylor, H.E.. Heavy Metals in the Mississippi River. 1995. http://pubs.usgs.gov/circ/circ1133/heavy-metals.html. *(accessed April 10, 2014).*

Giddings, E.M.; Hornberger, M.I.; Hadley, H.K. Trace-metal concentrations in sediment and water and health of aquatic macroinvertebrate communities of streams near Park City, Summit County, Utah. U.S. Geological Survey Water-Resources Investigations Report 01-4213, 2001.

Goyer, R.A. Toxic and essential metal interactions. Annual Review of Nutrition. 1997, 17, 37-50.

Gray, J.E.; Theodorakosa, P.M.; Bailey, E.A.; Turner, R.R. Distribution, speciation, and transport of mercury in stream-sediment, stream-water, *and fish collected near abandoned mercury mines in southwestern Alaska, USA. The Science of the Total Environment. 2000, 260, 21-33.*

Jara-Marini M.E.; Tapia-Alcaraz J.N.; Dumer-Gutiérrez J.A.; García-Rico L.; García-Hernández J.; Páez-Osuna F. Distribution and accumulation of Cd, Cu, Hg, Pb and Zn in the surface sediments of El Tobari Lagoon, central-East Gulf of California: An ecosystem associated with agriculture and aquaculture activities. Journal Of Environmental Science And Health. Part A, Toxic/Hazardous Substances & Environmental Engineering, 2013, 48 (14), 1842-1851

Journey,C. A.; Burns, D.A.; Riva-Murray, K.; Brigham, M.E.; Button, D.T.; Feaster, T.D.; Petkewich, M.D.;. Bradley, P.M. Fluvial Transport of Mercury, Dissolved Organic Carbon, Suspended Sediment, and Selected Major Ions in Contrasting Stream Basins in South Carolina and New York, October 2004 to September 2009. U.S. Geological Survey Scientific Investigations Report 2012–5173, Reston, Virginia, 2012.

Kyle, J.H.; Breuer, P.L.; Bunney, K.G.; Pleysier, R. Review of trace toxic elements (Pb, Cd, Hg, As, Sb, Bi, Se, Te) and their deportment in gold processing: Part II: Deportment in gold ore processing by cyanidation. Hydrometallurgy. 2012, 111-112(1), 10-21

Nagorski, S.A.; Neal, E.G.; Brabets, T.P. Mercury and Water-Quality Data from Rink Creek, Salmon Creek, and Good River, Glacier Bay National Park and Preserve, Alaska, November 2009–October 2011. U.S Geological Survey Open-File Report. 2013. Nriagu, J. O., Pacyna, J.M. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature . 1988, 333, 134 – 139

Nordstrom, D.K. Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters. Applied Geochemistry, 2011, 26, 1777-1791.

Prica, M.; Dalmacija, B.; Dalmacija, M.; Agbaba, J.; Krcmar, D.; Trickovic, J.; Karlovic, E. Changes in metal availability during sediment oxidation and the correlation with the immobilization potential. Ecotoxicology & Environmental Safety, 2010, 73 (6), 1370-1378

Schelker, J; Burns, D.A; Weiler, M; Laudon, H. Hydrological mobilization of mercury and dissolved organic carbon in a snow-dominated, forested watershed: Conceptualization and modeling. Journal Of Geophysical Research, 2011, 116, G01002

Scudder, B.C., Chasar, L.C., Wentz, D.A., Bauch, N.J., Brigham, M.E., Moran, P.W.; Krabbenhoft, D.P. Mercury in fish, bed sediment, and water from streams across the United States, 1998–2005. U.S. Geological Survey Scientific Investigations Report 2009–5109, 2009.

Seidel, H.; Mattusch, J.; Wennrich, R.; Morgenstern, P.; Ondruschka, J. Mobilization of arsenic and heavy metals from contaminated sediments by changing the environmental conditions. Acta Biotechnologica. 2002, 22(1-2), 153-160.

Sherrell, R.M.; Ross, J.M. Temporal variability of trace metals in New Jersey Pinelands streams: Relationships to discharge and pH. Geochimica Et Cosmochimica Acta. 1999, 63(19-20), 3321-3336.

Sidle, W.C.; Roose, D.L.; Barndt, P. Isotopic Evaluation of Pb Occurrences in the Rwerine Ecosystems of The Kankakee Watershed, Illinois-Indiana. Journal of The American Water Resources Association. 2001,37(2), 379-393.

Ugwu A.I. ; Wakawa R.J. ; La'ah E. ; Olotu A. Spatial Distribution of Heavy Metals in River Usuma Sediments and Study of Factors Impacting the Concentration. International Journal of Research and Reviews in Applied Sciences. 2012,12(2), 294-303.

Velimirović M.; Prica M.; Dalmacija B.; Rončević S.; Dalmacija M.;Bečelić M.; J. Tričković Characterisation, Availability, and Risk Assessment of the Metals in Sediment after Aging. Water Air Soil Pollution, 2011, 214, 219-229