

## The Impact of Anthropogenic Activities Recorded By Mercury in the Sediment from Dianshan Lake

<sup>1</sup>Hui Zhang, <sup>2</sup>Nan Zhang, <sup>1</sup>Qi Yang, <sup>1</sup>Lina Zhong and <sup>3</sup>Xu Zhang

<sup>1</sup>School of Environmental Science and Engineering,  
Shanghai Jiaotong University, 800 Dongchuan Rd., Shanghai 200240, PR China

<sup>2</sup>School of Medicine, Shanghai Jiaotong University,  
227 South Chongqing Rd., Shanghai 200025, P.R. China

<sup>3</sup>Department of Ecology and Environmental Protection,  
Shanghai Academy of Agricultural Sciences, 2901 Beizhai Rd., Shanghai 200220, PR China

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### ABSTRACT

The mercury in sediment cores from Dianshan Lake, Shanghai is studied in this study and it indicates that the mercury level changing from 52.78-145.66  $\mu\text{g kg}^{-1}$  in sediment can be obviously divided into three sections responding to the development of economy of Shanghai. Mercury decreases with depth in 0-11 cm underground, which is corresponding to the depositing period after 1980; and it is in less change with depth in 11-16 cm, which is corresponding to the period of middle 1960s-1980s. Below 16 cm Hg is decreasing with depth more obviously, which is corresponding to the period from the establishment of the People's Republic of China to the beginning of the Culture Revolution in 1970s. These indicate that the pollutants transported to the Dianshan Lake before 1980s are less than that after 1980 and in the period of 1970s Hg transportation to the Dianshan Lake is relatively decreasing with time. This mercury-increasing trend in the Dianshan Lake is consistent with the mercury release from coal combustion and non-coal sources in Yangtze Delta (mainly including Jiangsu, Zhejiang provinces and Shanghai) and is also a reflection of the economy development in Shanghai; It is, however, not associated that close to the protection of the lake. These facts indicate that the atmospheric deposition is probably the main source of mercury in the Dianshan Lake and the mercury level would probably be evidently increasing in this lake in certain period of time in the future even though protection efforts are now in process in Shanghai.

**Keywords:**Mercury Evolution, Dianshan Lake, Shanghai, Yangtze Delta, Environmental, Atmospheric Deposition, Culture Revolution

### 1. INTRODUCTION

Sediment has been considered as a steadier, real and exact monitoring medium for regional environmental quality and evolution trend than water body due to it is a main pollutant carrier for pollutant accumulation (Deyi, 1993). Pollutant caused by natural factors and human activities recorded in sediment could indicate not only the historical evolution of the anthropogenic pollution but also the effectiveness of protection efforts for historical periods.

The urban lake, Dianshan Lake is one of the most important water sources of Shanghai and its quality affects directly the drinking water safety of Shanghai. Some research work carried out on Hg pollution in water

system in Shanghai mainly focused on surface sediment including in Huangpu River, Suzhou creek and the Dianshan Lake (Xuying *et al.*, 2003; Din *et al.*, 2005; Wang, 2005). To understand the impact of Hg sources, pollution trend and environmental protection in water quality evolution in recent decades in Dianshan Lake, Shanghai, mercury recorded in the sediment of Dianshan Lake is studied in this study. From the concentration variation of Hg in sediment cores, the evolution trend of mercury in this lake and the development of the Yangtze Delta including Shanghai are discussed and the course of Hg pollution in the Dianshan Lake are probed. This study can offer assistance in protection of the water source and in the monitoring for Hg pollution effectively in Shanghai in the future.

## 2. MATERIALS AND METHODS

### 2.1. Research Area and Sampling Site

The Dianshan Lake is at the western margin of Shanghai (31°04'N-31°12'N and 120°54'E~121°01'E) as one of its most important water sources. It is located on the border of Shanghai, Jiangsu and Zhejiang provinces and is 60 km from the center of Shanghai. The Dianshan Lake belongs to Taihu Lake drainage area, southeastern China and it mainly receives the upstream water from Taihu Lake. From its downstream, the Huangpu River connects it to the Yangtze Rive to the China East Sea. Its area is 63.7 km<sup>2</sup> and the mean depth is about 2.1 m.

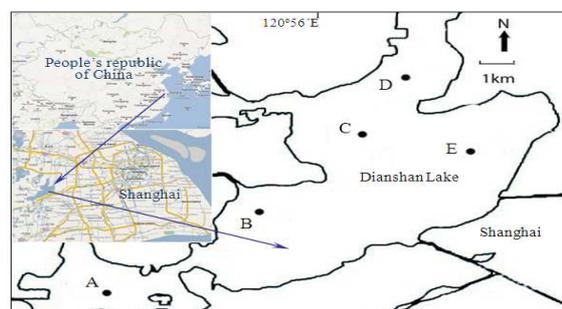
Five sampling sites were selected in the study area (**Fig. 1**). Site A is located at a relative closed area in the southwestern of the lake, site B is located at the depositing center near the infall of the lake, site C is located in the center of the Dianshan Lake where the sediment was relatively steady and undisturbed, site D is located near the aquatic field on the lake and site E is located in its north area.

### 2.2. Samples and Analysis

Five sediment cores were collected in sampling sites in December 2006 using an 8 cm-diameter and 4 m-long PVC tubes. The length of core A, B, C, D and E was 22, 26, 19, 26 cm and 48 cm respectively. The color of the cores is different in different depth as well as in different sites. Core E was fawn within 0-8 cm depth, green within 8-31 cm depth and gray within 31-48 cm depth. The other cores were all gray generally. There were some shells remained in the downside of core A and C. The sediment in upper 1-3 cm of each core was flocculent with more water and the bottom of cores was in light color.

Each core was sealed in the PVC tube with brown plastic bag and immediately transported to the lab where they were sectioned at intervals of 1 cm using bamboo flakes. All samples were dried at room temperature, triturated to 200<sup>#</sup> sieve by mortars and stored in study bags at 4°C until to be analyzed.

0.25 gram of every sample was taken into 25 ml test tubes and 10 mL reagent (HNO<sub>3</sub>/HCl=1/3) was added into the test tubes. The test tubes with lids were put into boiling water for 2 h with light shaking occasionally. These samples were diluted to 25 ml by deionized water. Blanks were also taken. AFS -9130 sequential injection atomic fluorescence spectroscopy (made in China) was used to detect the concentration of mercury. Instrument parameters in the experiments were as follows: Photomultiplier tube negative high voltage: 290V; Atomizer height: 8 mm; Lamp electric current: 30 mA; Carrier gas flow: 400 mL min<sup>-1</sup>; Shelter gas flow: 800 ml min<sup>-1</sup>.



**Fig. 1.** Sampling sites

All the polytetrafluoroethylene and glass containers used in the experiments were soaked in 10% nitric acid for more than 10 h, washed with deionized water and dried at 50°C in evaporation oven. The detecting limit for mercury was 0.001 µg L<sup>-1</sup>. Relative Standard Deviation (RSD) is 4.39% (n = 8).

## 3. RESULTS

The feature of the distribution of Hg in different depositing depth is shown as **Fig. 2**. The average concentrations at the same depth of five sediment cores were calculated and the result is shown in **Fig. 3**.

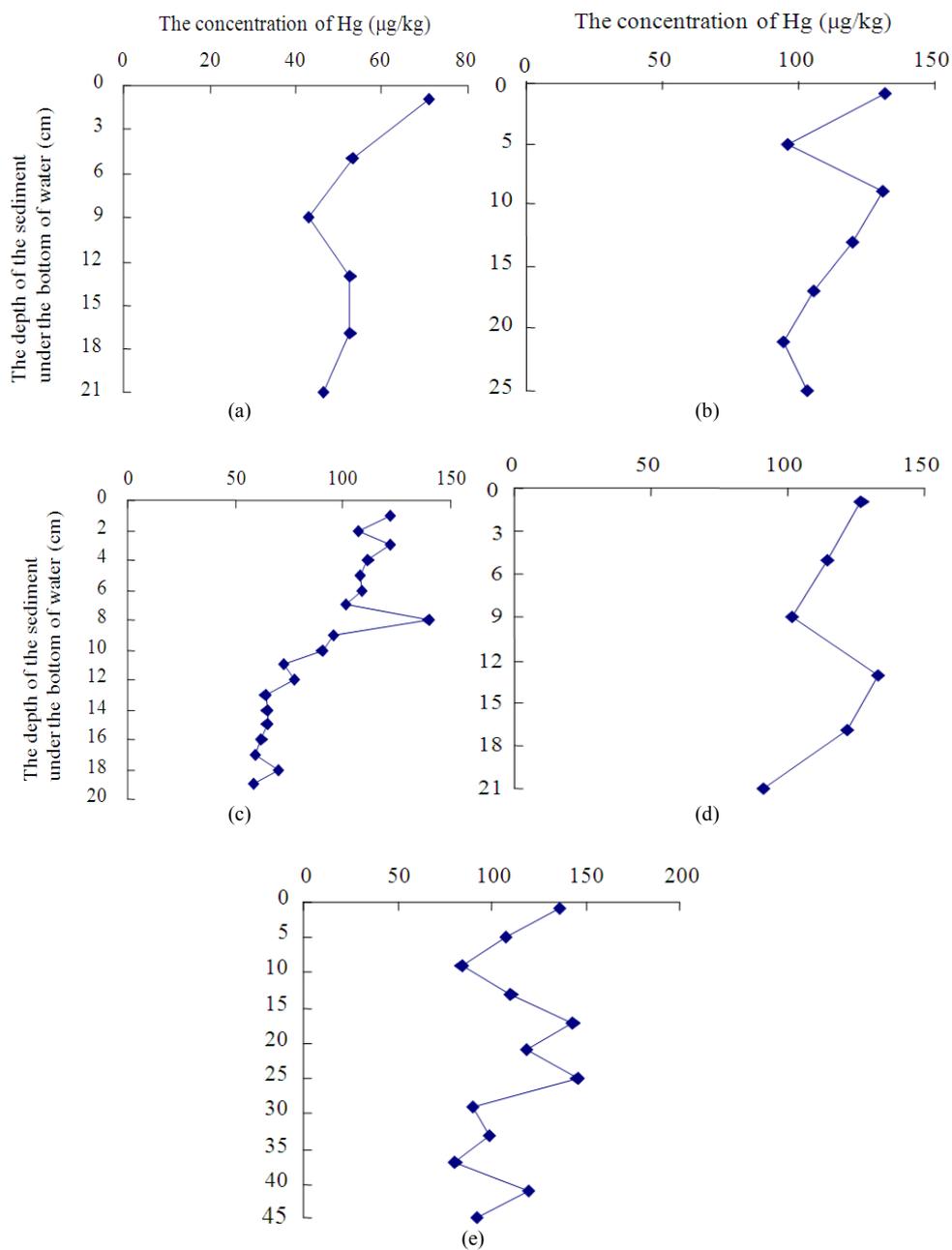
## 4. DISCUSSION

### 4.1. Mercury Distribution in the Sediment of the Dianshan Lake

In **Fig. 2**, it shows that the trends of the Hg concentration variation in the sediment cores from the Dianshan Lake are generally homologous. These features of 5 sediment sites indicate that Hg input and deposit rate were interrelated. In **Fig. 3**, it shows that the concentration of mercury changing with depth can be evidently divided into episode sections. The concentration of mercury in sediment decreases fast within depth in 0-9 cm section. The concentration variation of mercury in the section of the sediment below 9 cm decreases little with depth until 17 cm and below 17 cm it decreases with depth with a relative slower decreasing rate.

In the Yangtze Delta there are many lakes within about depth 1.5-4.8 m. These lakes are generally at the same geographical, depositing and weather conditions such as taihu Lake, dianshan lake, gehu lake and yangchenghu Lake (**Fig. 1**). And a lot of towns and villages with dense population are around these shallow lakes.

The average depositing rate at Taihu Lake was about 0.41 cm a<sup>-1</sup> (by <sup>210</sup>Pb CIC model and <sup>137</sup>Cs section) (Shuchun *et al.*, 2006) and the depositing velocity of lakes in China is between 0.1 cm a<sup>-1</sup> ~ 0.5 cm a<sup>-1</sup> (Jin, 1992). According to the data of Taihu Lake, which is one of the largest lakes in Yangtze Delta, the sediment dating of the Dianshan Lake is as **Fig. 3**.



**Fig. 2.** The distribution of Hg in the sediment from the Dianshan Lake

Judging by the lengths of the sediment cores, the studied cores recorded about 50 year depositing process. As **Fig. 3**, the concentration of mercury had quickly increased since the end of 1970s corresponding to the sediment above 9 cm, which indicated that abundant Hg was transported into the sediments in this depositing

period. The concentration of mercury in the section of the sediment below 9-17 cm decreases little with time, which was in correspondence with the depositing period of before 1980s to the end of 1960s. The Hg concentration of section below 17 cm increases slightly but obviously with time.

## 4.2. Sources for mercury in the Dianshan Lake

The Dianshan Lake locates at the border of Shanghai to Jiangsu and Zhejiang provinces (Fig. 1). By the Dianshan Lake, there were many agricultural fields and holiday cottages most of which were built after 1970s. Up to the 1984, there were 55 industrial pollutant source and 7 municipal pollutant source companies around the Dianshan Lake (Rengliang and Wang, 1993). From 1985, when water protection policy of Shanghai was applied to upstream Huangpu River including the Dianshan Lake, factories and warehouses without approval by the local administrative department of environmental protection had been closed down, suspended, or transferred to protect the water quality in Shanghai (Rengliang and Wang, 1993).

Comparing Hg in the Diashan Lake with that in other lake and rivers in the vicinity of the Yangtze Delta, the mercury average concentration in the sediment from the Dianshan Lake ( $99.06\mu\text{g kg}^{-1}$ ) is lower than that in the Taihu Lake ( $130.0\mu\text{g kg}^{-1}$ ), Huangpu River ( $204.03\mu\text{g kg}^{-1}$ ) (Din *et al.*, 2005) and Suzhou Creek ( $287.67\mu\text{g kg}^{-1}$ ) (Chen, 2006). Both Huangpu River and Suzhou Creek pass through the center town of Shanghai and the pollutants from city pollutant sources affected the sediments by the flow-off. The mercury concentration in the sediment of the Taihu Lake and rivers passing Shanghai combined with recent environmental protection actions around the lake suggest that the mercury in the Dianshan Lake do not mainly come from the surface runoff of Taihu Lake and bank sources, but seems from other source, the atmospheric deposition.

Mercury in sediments was mainly from discharge, surface runoff and atmospheric deposition (Qiao, 2004). In the atmosphere, mercury exists in three different forms: elemental mercury vapour ( $\text{Hg}^0$ ), gaseous divalent compounds ( $\text{Hg}^{2+}$ ) and being associated with particulate matter ( $\text{Hg}^p$ ). Over 80%~90% of mercury existed in the form of  $\text{Hg}^0$  and  $\text{Hg}^{2+}$ , while the percentage of  $\text{Hg}^p$  was lower than 10% (Pirrone and Wichmann-Fiebig, 2003). Considering the mobility in the atmosphere  $\text{Hg}^{2+}$  and  $\text{Hg}^p$  are regarded more readily deposited on local region via wet or dry processes (Schroeder and Munthe, 1998).

Coal combustion was the major source of mercury emission, which occupies 60% of the total mercury emission from human activities (Lindqvist, 1985). The mercury emission of coal combustion in the area surrounding the Dianshan Lake, Zhejiang, Jiangsu provinces and Shanghai in 2000 was 1.3-2.81 and 1.4

times higher than that in 1995 respectively (Qichao *et al.*, 1999). The average increasing rate was over 6% per year. The average non-coal mercury emissions of Zhejiang, Jiangsu provinces and Shanghai were 6.49, 4.80 and 2.48 tons respectively from 1995-2003 and of which the average increasing rate were 6%, 13% and 6% (Fig. 4) (Wang *et al.*, 2006). From 1978-1995, the mercury emission of coal combustion in China was increasing at the annual speed of 4.8% and the total emission of it was 2493.8 tons (Qichao *et al.*, 1999). The average mercury emission from non-coal sources in China increased 9 percent from 1995- 2003 (Wang *et al.*, 2006). The shares of elemental mercury ( $\text{Hg}^0$ ), oxidized mercury ( $\text{Hg}^{2+}$ ) and particulate mercury ( $\text{Hg}^p$ ) were sequentially 16%, 61%, 23% in the mercury emission of coal combustion and 77%, 18%, 5% in non-coal mercury emissions as shown in Fig. 4 (Wang *et al.*, 2006; Jiang *et al.*, 2005).

These data shows the mercury emission from coal combustion and non-coal combustion in Zhejiang, Jiangsu provinces and Shanghai had been increasing faster than all China's average rate in recent years and at the same time most of the  $\text{Hg}^p$  and  $\text{Hg}^{2+}$  would probably be transported into the water and soil near these areas by atmospheric deposition as reported by Alligui (2010). This may be the main reason of the gradually mercury increasing in the sediment of the Dianshan Lake.

## 4.3. Mercury in the Dianshan Lake and its Relationship with the Development in Shanghai

The general situation of economy development in shanghai is shown as Fig. 5 and 6. The trends correspond evidently with the features of Hg variation recorded in the sediment of the Dianshan Lake (Fig. 3).

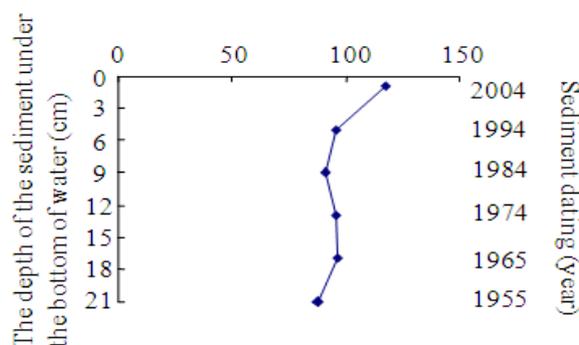
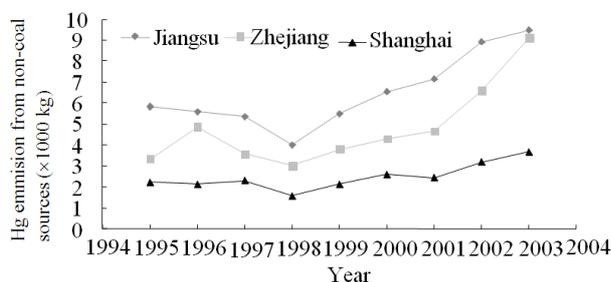
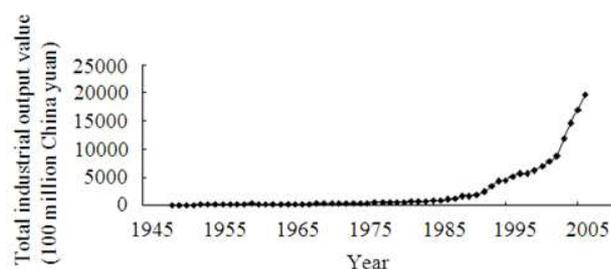


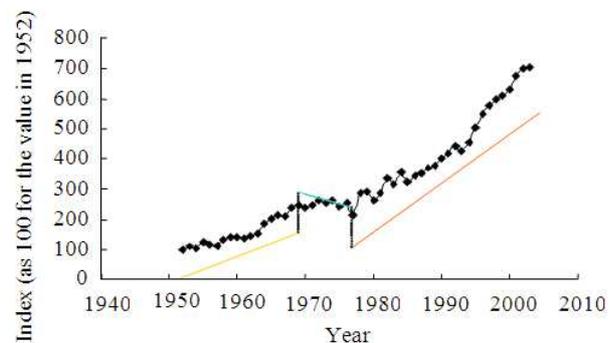
Fig. 3. The average concentration distribution and sediment dating of Hg in the sediment from the Dianshan Lake



**Fig. 4.** Mercury emission from non-coal sources in Jiangsu, Zhejiang provinces and Shanghai



**Fig. 5.** Variation of total industrial output value in Shanghai



**Fig. 6.** Variation of total agricultural output index in Shanghai

The mercury in sediments from the Dianshan Lake decreased with depth as mentioned above and corresponding to it industrial and agricultural output index curves of Shanghai showed a steady increase, especially that the variation of agriculture output index can be roughly divided into three obvious sections (**Fig. 6**). The depositing period from the end of 1970s, at 0-9 cm sediment section, corresponded with the enduring period of a fast economy development in Shanghai and all China after the reform and opening-up policy in

China. The depositing period below 9 cm until 17 cm was corresponding to the period of 1970s when China was in the Culture Revolution and in this period the development in economy slowed down throughout the whole country. The depositing period below 17 cm corresponded with the time before the Culture Revolution and the time after the establishment of the People's Republic of China which with a faster recovery and development of production after years of wars.

From the distribution of Hg in the sediment of the Dianshan Lake and the development in industry and agriculture in Shanghai, the Hg in the Dianshan Lake seems mainly from the atmospheric area sources affected heavily by Shanghai. At the same time, **Fig. 3** indicates that the protection in this district hasn't brought any visible reduction for Hg in the sediment after 1985. But, the fact that Hg is lower in the Dianshan lake sediment than in the Taihu Lake's implies that the protection for the Dianshan Lake is somehow effective. In other words, the Hg in the Dianshan Lake is not caused mainly by drainage from banks and, because of heavy adding rate of Hg in recent years, actions to prevent Hg being released in the lake had not got obvious effect. The variation characteristic of Hg in the sediment of the Dianshan Lake is the reflection of its special geographical location where Hg was not transported directly by flow-off from the center Shanghai but affected obviously by Shanghai.

The continued increase of mercury emission would probably cause the increase of mercury concentration in water and sediments as reported by Mark *et al.* (2004). On the other hand, even though the mercury emission decreased the mercury concentration in water and sediment would not decreased and this trend would affect the concentration of Hg in water and sediment when the Hg sources were stopped because of Hg's special behavior in environment (Tomiyasu *et al.*, 2000). In the case of Yatsushiro Sea, after the mercury source was shut down, the mercury concentration in sediments were decreased with the horizontal distance to its source, but not decreased obviously in the water and sediment in about 30 years as reported by Tomiyasu *et al.* (2000). The facts above suggest that the increase of mercury in the Dianshan Lake may be a combined result of mercury emission from its surrounding area, Yangtze Delta and the whole China. But the amount of Hg in the Dianshan Lake contributed by Shanghai was the most significant and the protective activity will not get an obvious result in decreasing Hg concentration in the Dianshan Lake at least in recent years.

## 5. CONCLUSION

Mercury in the Dianshan Lake is one of the most concerned problems in water environment protection in Shanghai and our study shows that its concentration is lower in Dianshan Lake sediment than that in other lakes and rivers nearby in Yangtze Delta. Mercury emission from coal combustion and non-coal sources in Yangtze Delta may be the main source of Hg in the lake. Shanghai's development in industry and agriculture heavily affected Hg variation in the lake. The protection on the banks is important to decrease Hg pollution in the Dianshan Lake. Taken together, atmospheric deposition was probably the most important cause of formation of the mercury in the lake. The Hg in the sediment will not be reduced obviously in a short period of time even though the protective efforts for Hg pollution in the lake continue.

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