Hg Content in Jiaozhou Bay from Atmosphere

Dongfang Yang\textsuperscript{1,2,3,a}, Danfeng Yang\textsuperscript{4}, Bailing Fan\textsuperscript{1,2}, Chunhua Su\textsuperscript{1,2}, Sixi Zhu\textsuperscript{1,2}

\textsuperscript{1}Research Center for Karst Wetland Ecology, Guizhou Minzu University, Guiyang, 550025, China
\textsuperscript{2}College of Chemistry and Environmental Science, Guizhou Minzu University, Guiyang, 550025, China
\textsuperscript{3}North China Sea Environmental Monitoring Center, SOA, Qingdao 266033, China
\textsuperscript{4}The Fu Foundation School of Engineering and Applied Science, Columbia University, 10025, USA.
\textsuperscript{a}dfyang_dfyang@126.com

Abstract: In May, August and October of 1991, the variation of Hg content in Jiaozhou Bay was 0.006-0.086\textmu g/L, which satisfies the Case I and II Sea Water Quality Standard, and there was mild or none pollution in Jiaozhou Bay, specifically, 0.010-0.061\textmu g/L in May, 0.021-0.086\textmu g/L in August and 0.006-0.074\textmu g/L in October, which were all mild pollution. It was mainly transported by ships and wharfs, atmospheric sedimentation and open sea current, 0.061\textmu g/L, 0.074-0.086\textmu g/L and 0.081\textmu g/L, respectively. The modelling diagram was established to display the different paths and contents of Hg in Jiaozhou Bay. Ships and wharfs were mainly mildly polluted by Hg content in May, atmospheric sedimentation and open sea current in August and atmospheric sedimentation in October. It showed that Hg content was transported by human in two ways. On the one hand, it was directly emitted by ships and wharfs to sea, which was low in content and short in period. On the other hand, it was discharged indirectly by human to sea in atmosphere, which was high and long. Thus, it is necessary to pay attention to the transport of Hg content in atmosphere, which was wide in space and long in period.

1. Introduction
Heavy metal, Hg, was used by human since the ancient times in a large number, and widely applied in the development of industry in modern times. Thus, a great number of Hg was discharged to the land, atmosphere and ocean in the process of production [1-14]. Hence, the study on the pollution and pollution source of Hg content in coastal waters provides significant reference for protecting marine environment and maintaining the sustainable development of the ecology. This paper, according to the investigation data in 1991, analyzed the Hg content, horizontal distribution and source in Jiaozhou Bay, and studied the water quality, source background and source amount of Hg, to provide scientific theoretical reference for the study on the source, pollution and transport of Hg in Jiaozhou Bay.

2. Study area and data collection
Study area. Jiaozhou Bay, located in southern Shandong Peninsula, is a typical semi-closed bay. The geographical location is 120°04'-120°23'E, 35°58'-36°18'N. Bounded by the line connecting Tuandao Cape and Xuejiadao Island, it connects with Yellow Sea, covering an area of about 446km\textsuperscript{2}, with the
average depth of about 7m. There are dozens of rivers reaching the ocean in Jiaozhou Bay, among of which, the rivers with a larger volume of runoff and sand content include Dagu River, Yang River, Haibo River in Qingdao, Licun River, Loushan River and so on. These rivers are seasonal streams, and hydrological characteristics vary seasonally [15, 16].

Data collection. The materials about Cu in Jiaozhou Bay waters in May, August and October of 1991 was provided by North China Sea Environment Monitoring Center, State Oceanic Administration. 13 sites were established: 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 2104, 2105 and 2106, shown in Figure 1. Samplings were performed for three times in August and October in 1991, respectively. According to the depth of water, sampling and survey were conducted (surface and bottom layers were sampled when the depth of water is more than 10m, but just surface layer when less than 10m). The survey on Cu of Jiaozhou Bay waters was in accordance with national standard method, which was included in The Specification for Marine Monitoring (1991) [17].

Fig.1 Investigation sites in Jiaozhou Bay

3. Results and discussion

The Hg content The Case I Sea Water Quality Standard of Hg content in sea water (0.05μg/L), Case II (0.20μg/L), Case IV (0.50μg/L) were put forward by the nation. In May, August and October of 1991, the variation of Hg content in Jiaozhou Bay was 0.006-0.086μg/L, which satisfies the Case I, II and IV Sea Water Quality Standard.

In May, the variation range of Hg content in Jiaozhou Bay was 0.010-0.061μg/L, shown in Table 1, and it reached 0.061μg/L in site 60 in the nearshore waters of northern bay mouth, satisfying the Case II Sea Water Quality Standard. It was lower in northeastern, northern, central and southwestern bay, less than 0.050μg/L, satisfying the Case I Sea Water Quality Standard.

In August, the variation range of Hg content in Jiaozhou Bay was 0.021-0.086μg/L, shown in Table 1. It reached 0.086μg/L in site 2106 in the nearshore waters of eastern bay, 0.081μg/L in site 55 in bay center and 0.081μg/L in site 52 in southern bay, satisfying the Case II Sea Water Quality Standard. It was lower in site 54 and 61 in southwestern bay and waters far away from estuary of Haribo River, satisfying the Case I Sea Water Quality Standard. It was higher in other waters, satisfying the Case II Sea Water Quality Standard.

In October, the variation range of Hg content in Jiaozhou Bay was 0.006-0.074μg/L, shown in Table 1, and it was highest in northeastern bay. The variation was 0.056-0.074μg/L in site 59, 58, 2105, 57 and 2106, satisfying the Case II Sea Water Quality Standard. It was the highest in site 2105, reaching 0.074μg/L. It was lower in other waters, satisfying the Case I Sea Water Quality Standard.

In May, August and October of 1991, the variation of Hg content in Jiaozhou Bay was 0.006-0.086μg/L, which satisfies the Case I and IISea Water Quality Standard, and there was mild or none pollution in Jiaozhou Bay(Tab 1).
Tab.1 The surface water quality in Jiaozhou bay in May and August

|                        | May     | August  | October |
|------------------------|---------|---------|---------|
| Hg Content in Sea Water/μg·L⁻¹ | 0.010-0.061 | 0.021-0.086 | 0.006-0.074 |
| National Sea Water Standard | Case I and II | Case I and II | Case I and II |

The horizontal distribution at surface In May, Hg content reached high as 0.061μg/L in site 60 in northern bay mouth, forming a series of parallel lines with different gradients. It decreased from 0.061μg/L in the center to the periphery, to 0.020μg/L in southwestern bay and 0.016μg/L in southwestern bay mouth(Fig. 2).

Fig.2 Hg content distribution at surface in Jiaozhou Bay in May(μg/L)

In August, Hg content reached high as 0.086μg/L in site 2106 in eastern bay, 0.081μg/L in site 55 in bay center and 0.081μg/L in site 52 in southern bay mouth, forming a series of semi-concentric circles, concentric circles and parallel lines with different gradients, respectively. It decreased from 0.086μg/L, 0.081μg/L and 0.081μg/L in the center to 0.063μg/L in northern bay, 0.045μg/L in southwestern bay and 0.045μg/L in southwestern bay(Fig. 3).

Fig.3 Hg content distribution at surface in Jiaozhou Bay in August(μg/L)

In October, Hg content reached high as 0.074μg/L in site 2105 in northeastern bay, forming a series of parallel lines with different gradients. It decreased from 0.074μg/L in the center to 0.037μg/L in southwestern bay and 0.006μg/L in southern bay mouth(Fig. 4).


Fig.4 Hg content distribution at surface in Jiaozhou Bay in October (μg/L)

**The water quality** In May, August and October of 1991, the variation of Hg content in Jiaozhou Bay was 0.006-0.086μg/L, which satisfies the Case I and II Sea Water Quality Standard, and there was mild or none pollution in Jiaozhou Bay.

In May, the variation range of Hg content in Jiaozhou Bay was 0.010-0.061μg/L, so Jiaozhou Bay was mildly polluted by Hg. It was larger than 0.050μg/L in the nearshore waters of northern bay mouth, satisfying the Case II Sea Water Quality Standard, and there was mild pollution from Hg. It was lower in other waters, satisfying the Case I Sea Water Quality Standard, and there was none pollution of Hg.

In August, the variation range of Hg content in Jiaozhou Bay was 0.021-0.086μg/L, so Jiaozhou Bay was mildly polluted by Hg. It was larger than 0.050μg/L in eastern bay, bay center and southern bay mouth, satisfying the Case II Sea Water Quality Standard, and there was mild pollution from Hg. It was lower in southwestern bay and waters far away from estuary of Haibo River, satisfying the Case I Sea Water Quality Standard, and there was none pollution of Hg. It was higher in other waters, satisfying the Case II Sea Water Quality Standard, and there was mild pollution from Hg.

In October, the variation range of Hg content in Jiaozhou Bay was 0.006-0.074μg/L, so Jiaozhou Bay was mildly polluted by Hg. It was larger than 0.050μg/L in northeastern bay, satisfying the Case II Sea Water Quality Standard, and there was mild pollution from Hg. It was lower in other waters, satisfying the Case I Sea Water Quality Standard, and there was none pollution of Hg.

**The source** In May, Hg was as high as 0.061μg/L in northern bay mouth, indicating that the source was ships and wharfs. In August, it was as high as 0.086μg/L in eastern bay and 0.081μg/L in bay center, indicating that the source was atmospheric sedimentation. Whereas, it was as high as 0.081μg/L in southern bay mouth, indicating that the source was open sea current. In October, it was as high as 0.074μg/L in northeastern bay, indicating that the source was atmospheric sedimentation.

In short, the Hg content of 0.061μg/L by ships and wharfs in May exceeded the Case I Sea Water Quality Standard of 0.05μg/L but satisfied the Case II Sea Water Quality Standard of 0.02μg/L, showing that ships and wharfs were mildly polluted by Hg content. The Hg content of 0.081-0.086μg/L by atmospheric sedimentation in August exceeded the Case I Sea Water Quality Standard of 0.05μg/L but satisfied the Case II Sea Water Quality Standard of 0.02μg/L, showing that atmospheric sedimentation was mildly polluted by Hg content. The Hg content of 0.081μg/L by open sea current in August exceeded the Case I Sea Water Quality Standard of 0.05μg/L but satisfied the Case II Sea Water Quality Standard of 0.02μg/L, showing that atmospheric sedimentation was mildly polluted by Hg content. The Hg content of 0.074μg/L by open atmospheric sedimentation in October exceeded the Case I Sea Water Quality Standard of 0.05μg/L but satisfied the Case II Sea Water Quality Standard of 0.02μg/L, showing that atmospheric sedimentation was mildly polluted by Hg content.

Tab.2 The Hg contents from the different sources in Jiaozhou bay

| Time   | May       | August     | October    |
|--------|-----------|------------|------------|
| Different sources | Ships and Atmospheric | Open sea Atmospheric |          |
The modelling diagram was established in Figure 5 to display the different paths and contents of Hg in Jiaozhou Bay. In this way, the transport process of Hg content by human to the atmosphere and ocean was disclosed in a quantitative way.

### The varied contents transported

In May and October, the sources were less and Hg contents transported to Jiaozhou Bay were lower, with 0.061μg/L by ships and wharfs and 0.074μg/L by atmospheric sedimentation, respectively, showing that there was less source and mild pollution. Whereas, in August, the sources were more and Hg contents were higher, with 0.081-0.086μg/L by atmospheric sedimentation and 0.081μg/L by open sea current at the same time, showing that there were diversified sources and mild pollution.

In May, ships and wharfs were mildly polluted by Hg content, showing that Hg content was directly discharged by ships and wharfs to sea. However, the Hg content was lower in amount and short in period, that is, one month. Thus, Hg content discharged by human was decreasing and ships and wharfs were mildly polluted by Hg content.

In June, atmospheric sedimentation and open sea current were mildly polluted by Hg content, showing that Hg content discharged by human to atmosphere was higher, causing increasing transport paths of Hg content. On the one hand, Hg content discharged to atmosphere was increasing widely. On the other hand, it was discharged to sea for a long time, resulting in the increasing Hg content at sea and mild pollution.

In October, atmospheric sedimentation was mildly polluted by Hg content, showing that Hg content endured from August to October. Besides, it was high in content and longer in period.

In August, the variation of Hg content in Jiaozhou Bay was 0.006-0.086μg/L, which satisfies the Case I and II Sea Water Quality Standard, and there was mild or none pollution in Jiaozhou Bay.

In May, the variation range of Hg content in Jiaozhou Bay was 0.010-0.061μg/L, so there was mild pollution from Hg in nearshore waters of northern bay mouth. In other waters, there was none pollution of Hg.

In August, the variation range of Hg content in Jiaozhou Bay was 0.021-0.086μg/L, so there was none pollution of Hg.

### Conclusion

In May, August and October of 1991, the variation of Hg content in Jiaozhou Bay was 0.006-0.086μg/L, which satisfies the Case I and II Sea Water Quality Standard, and there was mild or none pollution in Jiaozhou Bay.
mild pollution from Hg in eastern bay, bay center and southern bay mouth. In southwestern bay and waters far away from estuary of Haibo River, there was none pollution of Hg.

In October, the variation range of Hg content in Jiaozhou Bay was 0.006-0.074μg/L, so Jiaozhou Bay was mildly polluted by Hg. There was mild pollution from Hg in northeastern bay. In other waters, there was none pollution of Hg.

It was mainly transported by ships and wharfs, atmospheric sedimentation and open sea current, 0.061μg/L, 0.074-0.086μg/L and 0.081μg/L, respectively. The modelling diagram was established in Figure 5 to display the different paths and contents of Hg in Jiaozhou Bay. In this way, the transport process of Hg content by human to the atmosphere and ocean was disclosed in a quantitative way. Therefore, there was mild pollution in ships and wharfs in May, atmospheric sedimentation and open sea current in August, and atmospheric sedimentation in October.

Hg content was transported by human in two ways. On the one hand, it was directly emitted by ships and wharfs to sea, which was low in content and short in period. On the other hand, it was discharged indirectly by human to sea by atmospheric sedimentation, which was high in content and longer in period. After diversified sources and longer period, the ocean was mildly polluted by Hg content, and the sea water with mild pollution of Hg content would continue to pollute new clean waters. Thus, it is necessary to pay attention to the transport of Hg content in atmosphere, which was wide in space and long in period.

Acknowledgement
This research was sponsored by Doctoral Degree Construction Library of Guizhou Nationalities University and Research Projects of Guizhou Nationalities University ([2014]02), Research Projects of Guizhou Province Ministry of Education (KY [2014] 266), Research Projects of Guizhou Province Ministry of Science and Technology (LH [2014] 7376).

References
[1] Dongfang Yang, Zhenhui Gao, Marine Bay Ecology [M]. Beijing, China Education Culture Pressing House, 2006.
[2] Dongfang Yang, Zhenhui Gao, Marine Bay Ecology (I) [M]. Beijing, China Ocean Press, 2010.
[3] Dongfang Yang, Zhenqing Miao, Marine Bay Ecology (II) [M]. Beijing, China Ocean Press, 2010.
[4] Yu Chen, Zhenhui Gao, Yanheng Qu, Dongfang Yang and Hongxia Tang. Mercury distribution in the Jiaozhou Bay[J]. Chin. J. Oceanol. Limnol. 2007, 25(4): 455-458.
[5] Dongfang Yang, Hairong Cai, Zhenhui Gao, Qing Lu, Yanfeng Qu. The Distribution and Transport of Hg in Jiaozhou Bay[J]. Marine Environmental Science, 2008, 27(1): 37-39.
[6] Dongfang Yang, Leilei Wang, Zhenhui Gao, Lian Ju, Jiping Zeng. The Distribution and Pollution Source of Hg in Jiaozhou Bay[J]. Marine Environmental Science, 2009, 28(5): 501-505.
[7] Yu Chen, Yinjiang Zhang, Junhui Guo, Qiang Shi, Dongfang Yang. The Distribution and Seasonal Variation of Hg in Jiaozhou Bay[J]. Ocean Development and Management, 2013, 30(6): 81-83.
[8] Dongfang Yang, Peiyun Sun, Lian Ju, Yuhui Zhao, Yanfeng Qu. The Quality Concentration and Distribution of Hg in Jiaozhou Bay[J]. Coastal Engineering, 2013, 32(4): 65-76.
[9] Dongfang Yang, Zijun Xu, Yanfeng Qu, Yanrong Zhou, Fei Teng. The Distribution and Input Path of Hg in Jiaozhou Bay[J]. Coastal Engineering, 2014, 33(1): 67-78.
[10] Yu Chen, Yanfeng Qu, Renlin Pei and Dongfang Yang. Effect of Hg in Jiaozhou Bay waters- The aquatic transfer process[J]. Advanced Materials Research Vols.955-959. 2014, 2491-2495.
[11] Dongfang Yang, Sixi Zhu, Fengyou Wang, Xiuxin Yang and Yunjie Wu. Effect of Hg in Jiaozhou Bay waters- The land transfer process[J]. Advanced Materials Research Vols.955-959. 2014, 2496-2500.
[12] Dongfang Yang, Sixi Zhu, Fengyou Wang, Huazhou He and Yunjie Wu. Effect of Hg in Jiaozhou Bay waters- The Temporal variation of the Hg content[J]. Applied Mechanics and Materials Vols.556-562. 2014, 633-636.
[13] Dongfang Yang, Fengyou Wang, Huazhong He, Youfu Wu and Sixi Zhu. Effect of Hg in Jiaozhou Bay waters- The change process of the Hg pollution sources[J]. Advanced Materials Research Vols.955-959. 2014, 1443-1447.

[14] Yang Dongfang, Geng Xiao, Qu Yanfeng, Bai Hongyan, Xu Zijun. The Distribution and Gravity Features of Hg in Jiaozhou Bay [J]. Ocean Development and Management, 2014, 31(12): 71-77.

[15] D FYANG, Y CHEN, Z HGAO, et al. Silicon Limitation on primary production and its destiny in Jiaozhou Bay, China IV transect offshore the coast with estuaries [J]. Chin. J. Oceanol. Limnol. 2005, 23(1): 72-90.

[16] Dongfang Yang, Fan Wang, Zhenhui Gao et al. Ecological phenomena of phytoplankton in Jiaozhou Bay [J]. Marine Sciences, 2004, 28(6): 71-74.

[17] State Oceanic Administration. The Specification for Marine Monitoring [Z]. Beijing: China Ocean Press, 1991.