Yang’s dynamic vertical balance theory: application on Hg’s vertical changes in Jiaozhou Bay

Dongfang Yang1,2,a, Xiyang Song3, Ming Feng1,Linzhen Wei1, Tao Jiang1
1School of International Economics, Shaanxi Institute of International Trade & commerce, Xi’an, 712046, China;
2North China Sea Environmental Monitoring Center, SOA, Qingdao 266033, China;
3 Shaanxi University of Technology, Hanzhong, 723000, China.

a dfyang_dfyang@126.com

Abstract. Using investigation on Mercury (Hg) in May and August 1990, this paper analyzed the horizontal and vertical migration changes of Hg contents, and quantified the horizontal loss, vertical dilution and vertical accumulation amounts. Results showed that the absolute horizontal loss amount and relative horizontal loss amount were 0.002-0.015 μg L⁻¹ and 3.63-15.87%, respectively. The absolute dilution amount and relative dilution amount were 0.000-0.005 μg L⁻¹ and 0.00-2.57%, compared to absolute accumulation amount and relative accumulation amount of 0.008 μg L⁻¹ and 12.69%, respectively. Once Hg was transporting through the bay, there were small horizontal losses in both surface and bottom waters. The horizontal loss in bottom waters would be small/big in case of the horizontal loss in surface waters was small/big. No matter Hg contents in waters were relative high or relative low, the sediment of Hg from surface waters to bottom waters was very rapid, and the vertical loss during the vertical migration process was very small, resulting in almost all of the Hg was moving to the sea bottom. Finally, this paper provided Yang’s dynamic vertical balance theory to reveal the vertical migration process of substance in marine bay.

1.Introduction
Hg pollution has been one of the critical environmental issues in many marine bays due to the lagging of waste treatment to the rapid increasing of industry [1-3]. Understanding the migration process of Hg in marine bay is essential to environmental protection and remediation [4-5]. Jiaozhou Bay is a semi-closed bay located in Shandong Province, China. This bay is surrounded by cities of Qingdao, Jiaozhou and Jiaonan. The industry and economic were developing rapidly since 1980s and the environmental pollution problem was rising due to the lagging of waste treatment from waste generating [6-15]. Using investigation on Mercury (Hg) in May and August 1990, this paper analyzed the horizontal and vertical migration changes of Hg contents, and quantified the horizontal loss, vertical dilution and vertical accumulation amounts. Furthermore, this paper provided Yang’s dynamic vertical balance theory to reveal the vertical migration process of substance in marine bay. The aim of this paper is to provide scientific basis for research on the migration process of pollutants in marine bay.
2. Materials and method

2.1 Study area. Jiaozhou Bay (120°04′-120°23′ E, 35°55′-36°18′ N) is located in the south of Shandong Province, eastern China (Fig. 1). It is a semi-closed bay with the total area, average water depth and bay mouth width of 446 km², 7 m and 3 km, respectively. There are more than ten inflow rivers such as Haibo River, Licun River, and Loushan River [15-16].

2.2 Data source. The data was provided by North China Sea Environmental Monitoring Center. The investigations were conducted in May and August 1990, respectively. Surface and bottom water samples in 2 sampling sites (i.e., 55 and 60) were collected and measured followed by National Specification for Marine Monitoring (Fig. 1) [17].

![Geographical location and sampling site in Jiaozhou Bay](image)

Fig. 1 Geographical location and sampling site in Jiaozhou Bay

2.3 Modelling for horizontal loss. The contents of the substances in waters in marine bays were changing continuously water exchange between the open waters and the internal waters in the bay [15-18]. Site 55 is located in the bay center, while Site 66 is located in the north of the bay mouth. Supposed that substance contents in surface and bottom waters in the bay center are $A$ and $a$, in the bay mouth are $B$ and $b$, respectively.

In surface waters, and from the bay center to the bay mouth, the calculation formula for migration process is:

$$D = A - B, \quad E = (100 \times \frac{|A - B|}{\max(A, B)})\%$$

where, $D$ is the horizontal absolute loss amount in surface waters, $E$ is the horizontal relative loss amount.

In bottom waters, and from the bay center to the bay mouth, the calculation formula for migration process is:

$$d = a - b, \quad e = (100 \times \frac{|a - b|}{\max(a, b)})\%$$
where, $d$ is the horizontal absolute loss amount in surface waters, $e$ is the horizontal relative loss amount.

2.4 Modelling for vertical loss. Supposed that substance contents in surface and bottom waters in a certain sampling site (e.g., Site 55 in the bay center) are $A$ and $a$, respectively. From surface waters to bottom waters, the calculation formula for this migration process is:

$$V_{na} = A - a, \quad V_{nr} = \left(100 \times \left| \frac{A - a}{\max(A, a)} \right| \right)\%$$

(3)

where, $V_{na}$ is the horizontal absolute dilution amount from surface waters to bottom waters, $V_{nr}$ is the horizontal relative dilution amount. While from bottom waters to surface waters, $V_{na}$ refers to the horizontal absolute accumulation amount, and $V_{nr}$ refers to the horizontal relative accumulation amount.

3. Results

3.1 Horizontal change. The horizontal migration process of Hg in surface waters in Jiaozhou Bay were calculated in accordance to Hg contents in Site 55 in the bay center and Site 66 in the north of the bay mouth. The horizontal losses of Cr in surface and bottom waters were calculated and listed in Table 1.

| Month  | Surface waters $D/\mu g \, L^{-1}$ | Surface waters $E/%$ | Bottom waters $d/\mu g \, L^{-1}$ | Bottom waters $e/%$ |
|--------|-----------------------------------|----------------------|-----------------------------------|----------------------|
| May    | 0.014                             | 6.73                 | 0.015                             | 7.35                 |
| August | 0.002                             | 3.63                 | 0.010                             | 15.87                |

Table 1: Horizontal loss of Cd from Site 55 to Site 66 in Jiaozhou Bay

3.2 Vertical change. The vertical migration processes of Cd in waters in Jiaozhou Bay were calculated in accordance to Cd contents in Site 55 in the bay center and Site 66 in the north of the bay mouth. The horizontal losses of Cd were calculated and listed in Table 2.

| Month | Site | $V_{na}/\mu g \, L^{-1}$ | $V_{nr}/%$ |
|-------|------|-------------------------|-----------|
| May   | 55   | 0.004                   | 1.92      |
|       | 66   | 0.005                   | 2.57      |
| August| 55   | -0.008                  | 12.69     |
|       | 66   | 0.000                   | 0.00      |

Table 2: Vertical loss of Cd in Jiaozhou Bay

4. Discussion

4.1 Vertical and horizontal changes. The vertical and horizontal changes during migration process of substances in marine bay were determined by source input and vertical and horizontal water’s effect [16-18]. The major Hg source in Site 55 in the center of the bay was atmosphere deposition whose source strength was 0.055-0.208 $\mu g \, L^{-1}$, while major Hg source in Site 60 in the north of the bay mouth was the wharf whose source strength was 0.053-0.194 $\mu g \, L^{-1}$ (Table 1). In May 1990, from the center of the bay to the north of the bay mouth, the horizontal loss of Hg contents in surface waters and bottom waters were relative low as 6.73% and 7.35%, respectively (Fig. 2). Meanwhile, the vertical dilution amount in the center of the bay was also very low as 1.92%, compared with 2.57% in the north of the bay mouth (Fig. 2). In August 1990, from the center of the bay to the north of the bay mouth, the horizontal loss of Hg contents in surface waters and bottom waters were 3.63% and 15.87%, respectively (Fig. 3). Meanwhile, the vertical accumulation amount in the center of the bay was 12.69%, while the vertical dilution amount in the north of the bay mouth was 0.00% (Fig. 3).
4.2 Vertical and horizontal losses. Taking the center of the bay and the north of the bay mouth as the starting point and the end point, respectively. The horizontal loss amounts of Hg contents in surface waters in May and August were 6.73% and 3.63%, compared with 7.35% and 15.87% in bottom waters, respectively. It could be found that once Hg was transporting through the bay, there were small horizontal losses in both surface and bottom waters. The horizontal loss in bottom waters would be small/big in case of the horizontal loss in surface waters was small/big. In May 1990, Hg contents in surface waters and bottom waters were 0.194-0.208 μg L⁻¹ and 0.189-0.204 μg L⁻¹, respectively. In August 1990, Hg contents in surface waters and bottom waters were 0.053-0.055 μg L⁻¹ and 0.053-0.063 μg L⁻¹, respectively. By comparison, Hg contents in May were relative higher than in August. In May, the vertical dilution amount in the center of the bay was relative low as 1.92%, compared with 2.57% in the north of the bay. It could be concluded that the relative high Hg contents in surface waters were moving rapidly from surface waters to sea bottom, and there was little vertical loss, and the sediment process of Hg was thorough. In August, the vertical dilution amount in the center of the bay was 12.69%, compared with 0.00% in the north of the bay. It could be concluded that the relative low Hg contents in surface waters were moving rapidly from surface waters to sea bottom, and there was little vertical loss, and the sediment process of Hg was thorough.
4.3 Dynamic vertical balance process. By means of tide, current and gravity, Hg contents were decreasing from the source input location to waters far away. Sit 55 was located in waters in the center of the bay, in where was the location of source input by atmosphere deposition. In this location, the vertical dilution amount was very low (1.92%) in May, yet after three months the vertical dilution was changed to vertical accumulation (12.69%) in August. Meanwhile, Hg contents in surface waters were changed from 0.208 μg L⁻¹ in May to 0.055 μg L⁻¹ in August. During the changing process from vertical dilution to vertical accumulation, there must be a dynamic vertical balance point, in which the vertical dilution amount is 0. This dynamic vertical balance point, is to say, Yang’s Dynamic Vertical Balance Point. For instance, in waters in the center of the bay, from May to August, a dynamic vertical balance point used to be occurring, in which the vertical dilution amount is 0 (Fig. 2). Another example, in waters in the north of the bay mouth, from May to August, a dynamic vertical balance point also used to be occurring, in which the vertical dilution amount is 0 (Fig. 3).

5. Dynamic vertical balance theory.
At temporal scale, substance contents are highest in waters in the source input position, meanwhile the vertical dilution amounts are also highest. That’s the starting point of dynamic vertical balance of substance. As time passing bay, the sediment is rapid and continuous, resulting in the decreasing of substance contents in surface waters and the decreasing or vertical dilution amounts. That’s the balancing process. Finally, at one moment, the vertical dilution amounts of substance contents are decreasing to 0, and the substance is homogeneous in waters. This is the end point of dynamic vertical balance of substance. The moment is called Yang’s dynamic vertical balance time, and the content at this moment is named Yang’s dynamic vertical balance value. At spatial scale, substance contents are highest in waters in the source input position, meanwhile the vertical dilution amounts are also highest. That’s the starting point of dynamic vertical balance of substance. As the distance from the source input position is increasing, the sediment is rapid and continuous, resulting in the decreasing of substance contents in surface waters and the decreasing or vertical dilution amounts. That’s the balancing process. Finally, at one position, the vertical dilution amounts of substance contents are decreasing to 0, and the substance is homogeneous in waters. This is the end position of dynamic vertical balance of substance. This position is called Yang’s dynamic vertical balance position, and the content at this position is named Yang’s dynamic vertical balance value.

6. Conclusion
Once Hg was transporting through the bay, there were small horizontal losses in both surface and bottom waters. The horizontal loss in bottom waters would be small/big in case of the horizontal loss in surface waters was small/big. No matter Hg contents in waters were relative high or relative low, the sediment of Hg from surface waters to bottom waters was very rapid. The vertical loss during the vertical migration process was very small, resulting in almost all of the Hg was moving to the sea bottom. During the changing process from vertical dilution to vertical accumulation, there must be a dynamic vertical balance point, in which the vertical dilution amount is 0. This dynamic vertical balance point is to say, Yang’s Dynamic Vertical Balance Point.

At temporal scale, during the vertical balancing process, there is a moment in which the vertical dilution amounts of substance contents are decreasing to 0, and the substance is homogeneous in waters. The moment is called Yang’s dynamic vertical balance time. At spatial scale, during the vertical balancing process, there is a position in where the vertical dilution amounts of substance contents are decreasing to 0, and the substance is homogeneous in waters. This position is called Yang’s dynamic vertical balance position. The content at this moment or the position is named Yang’s dynamic vertical balance value.

Acknowledgement
This research was sponsored by Doctoral Degree Construction Library of Guizhou Nationalities University, 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] Chen Y, Gao ZH, Qu YH, et al.: Chinese Journal of Oceanology Limnology, Vol. 25(2007), p. 455-458.
[2] Yang DF, Cao HR, Gao ZH, et al.: Ocean Environmental Science, Vol. 27 (2008), p. 37-39.
[3] Yang DF, Wang LL, Gao ZH, et al.: Ocean Environmental Science, Vol. 28 (2009), p. 501-505.
[4] Chen Y, Zhang YJ, Gao JH, et al.: Ocean Development and Management, Vol. 30 (2013), p. 81-83.
[5] Yang DF, Sun PY, Ju L, et al: Coastal Engineering, Vol. 32(2013), p.65-76.
[6] Yang DF, Xu ZJ Qu YF, et al.:Coastal Engineering, Vol. 33(2014), p. 67-78.
[7] Chen Y, Qu YF, Pei RL, et al.:Advanced Materials Research, Vol.955-959 (2014), p. 2491-2495.
[8] Yang DF, Zhu SX, Wang FY, et al.:Advanced Materials Research, Vol.955-959(2014), p. 2496-2500.
[9] Yang DF, Zhu SX, Wang FY, et al.:Applied Mechanics and Materials, Vol.556-562 (2014), p. 633-636.
[10] Yang DF, Wang FY, He HZ, et al.: Advanced Materials Research, Vol.955-959(2014),p. 1443-1447.
[11] Yang DF, Geng X, Qu YT, et al.: Ocean Development and Management, Vol. 31 (2014), p. 71-77.
[12] Yang DF, Chen Y, Gao ZH, et al.: Chinese Journal of Oceanology and Limnology, Vol. 23(2005), p. 72-90.
[13] Yang DF, Wang F, Gao ZH, et al. Marine Science, Vol. 28 (2004), p. 71-74.
[14] China's State Oceanic Administration: The specification for marine monitoring (Ocean Press, Beijing 1991), p.1-300.
[15] Yang DF, Miao ZQ, Xu HZ, et al.: Marine Environmental Science, Vol. 32 (2013), p.373-380.
[16] Yang DF, Miao ZQ, Xu GZ, et al.: Proceedings of the 2015 international symposium on computers and informatics, 2015, p. 2655-2660.
[17] Yang DF, Wang FY, Zhao XL, et al.: Sustainable Energy and Environment Protection, 2015, p. 191-195.
[18] Yang DF, Wang FY, Yang XQ, et al.: Advances in Computer Science Research, Vol. 2352 (2015), p. 198-204.