Identification of coastal water quality by multivariate statistical techniques in two typical bays of northern Zhejiang Province, East China Sea

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Abstract
The Hangzhou Bay (HVB) and Xiangshan Bay (XSB), in northern Zhejiang Province and connect to the East China Sea (ECS) were considerably affected by the consequence of water quality degradation. In this study, we analyzed physical and biogeochemical properties of water quality via multivariate statistical techniques. Hierarchical cluster analysis (HCA) grouped HVB and XSB into two subareas of different pollution sources based on similar physical and biogeochemical properties. Principal component analysis (PCA) identified three latent pollution sources in HVB and XSB respectively and emphasized the importance of terrestrial inputs, coastal industries as well as natural processes in determining the water quality of the two bays. Therefore, proper measurement for the protection of aquatic ecosystem in HVB and XSB were of great urgency.

Key words: coastal water quality, Hangzhou Bay, Xiangshan Bay, hierarchical cluster analysis, principal component analysis, latent pollution sources


1 Introduction
Locating in the western coast of the East China Sea (ECS) and being the dominant part of the Yangtze River Delta Economic Zone, the northern Zhejiang Province enjoys unique regional advantages over marine economic development. The gross ocean product of Zhejiang Province has reached 494.75 billion RMB, ranking the third among China’s eleven coastal regions and accounting for 14.3% of its gross regional product over the past two years (SOA, 2014). However, the rapid economic growth has resulted in massive discharges of wastes (e.g., excess nutrient emissions, organic pollutants, heavy metals), which eventually led to the deterioration of water quality. According to the Oceanic and Fishery Administration of Zhejiang Province (OFAZP, 2014), water quality of coastal northern Zhejiang Province, particularly the Hangzhou Bay (HVB) and the Xiangshan Bay (XSB), is inferior to the fourth-class (the worst) in recent years per the seawater quality standard of China (GB 3097-1997). Furthermore, harmful algal blooms (HABs) accidents occurred frequently (18 times from May to August in 2014), affected 1 720 km2 sea area (OFAZP, 2015). Apparently, the marine environment of coastal northern Zhejiang suffered from tremendous environmental stresses. Coastal waters are of great importance from the ecological point of view because of its higher primary production and biodiversity compared with open sea areas (Pauly et al., 2002). The productive coastal areas serve as habitats for a variety of marine organisms, the important resources of commercial fisheries. The majority of the global coastal environments are affected by eutrophication and HABs, often as a result of rises in nutrients driven anthropogenically (Anderson et al., 2002). Being a vital part of coastal marine ecosystems, estuaries and bays experience both point and non-point pollution (e.g., industrial effluent, domestic sewage, agricultural wastewater, soil erosion and atmospheric deposition) due to their connections to the lands. The abundant pollutants make them more susceptible to various environmental factors (Valiela et al., 1992; Bianchi and Allison, 2009; Paerl, 1997). Overall, the degradation of coastal water quality will not only threaten the living environment of marine organisms but also the health of human beings. It is essential to evaluate coastal water quality to understand the temporal-spatial variations of physical and biogeochemical parameters and identify major potential pollution sources for the purpose of marine environmental protection.

Traditional methods of water quality assessment mainly consist of the direct evaluation of chemical, physical properties and indirect methods using biological indicators (Borja and Dauer, 2008). For instance, Gao et al. (2011) and Cai et al. (2013) demonstrated that the excess riverine inputs of nitrogen characterized with high N/P ratio and nutrients released from aquaculture industries resulted in severe eutrophication in HVB and XSB. Based upon meta-analysis of phytoplankton biodiversity, Zhou et al. (2010) argued that HVB was under increasing ecological risk. Though these studies partly reflect the environmental situation, it is inherently difficult to extract the components and possible causes of temporal-spatial variability when large amount of dataset is presented (Bierman et al., 2011). However, statistical tech-
2 Materials and methods

2.1 Study areas

Both HZB and XSB are situated in the subtropical monsoon area characterized with humid temperate climate. The annual precipitation reached 1 500 mm of which more than 50% occurs between May and August (Gao et al., 1993; Su and Yuan, 2005). During spring and summer, the two bays are affected by significant circulation and water masses, including the Changjiang Diluted Water (CDW) and Taiwan Warm Current (TWC). The former flows southward alongside the coast as a small branch and the latter moves northward along the continental slope of the East China Sea (Su and Yuan, 2005).

HZB is a funnel-shaped macro-tidal embayment with an area of 5 000 km² and mean depth of 10 m. It comprises a coastline of 258 km, 100 km ranging from the southern coast to the north and 90 km from the east to the west. The semi-diurnal tide is the main driving force behind the horizontal water flow in the bay, with the M₂ constituent being the dominant tidal component (China’s bays compilation committee (CSCC), 1992; Zhang et al., 2015). The Qiantang River (QTR) is the main river system flowing eastward into the bay, with the annual mean runoff of 20.95×10¹⁰ m³/a and sediment load of 2.91×10⁸ t/a, respectively (data available at http://www.irtces.org/nishagb_2012.asp). The Qiantang River (Yangtze River) is another major river that partly discharging into the bay, with the annual mean runoff of 896.4×10¹⁰ m³/a and sediment load of 3.9×10⁸ t/a, respectively (data available at http://www.irtces.org/nishagb_2012.asp). The Qiantang River (Yangtze River) is another major river that partially discharging into the bay, with the annual mean runoff of 896.4×10¹⁰ m³/a and sediment load of 3.9×10⁸ t/a, respectively (data available at http://www.irtces.org/nishagb_2012.asp).
spatial and temporal significant differences of all the physical and biogeochemical parameters.

HCA was employed for the classification of sampling sites into subgroups via standardized dataset (mean 0, standard deviation 1) based upon similar physical and biogeochemical properties. Here, HCA was conducted by Ward’s method using squared Euclidean distance. The final results were illustrated through dendrograms to visualize similarity among stations.

PCA was performed to analyze the tempospatial variations of water quality and identify potential pollution sources in this study. Prior to PCA, all the datasets should be standardized to have an average of 0 and a standard deviation of 1 so as to eliminate the differences in determination units and concentrations of variables. The process reduced the dimensionality of the variable space by identifying correlation structures within a data matrix and included the reduction of various parameters into few components (Jenerette et al., 2002). The criterion with eigenvalue greater than 1 was applied to the extracted principal components (PCs). Component loadings with values greater than 0.7, 0.5–0.7 and 0.3–0.5 referred to “strong”, “moderate” and “weak” relationships between PCs and variables, respectively (Liu et al., 2003).

Dataset used for HCA and PCA were combined from the two sampling cruises. All the statistical analyses were carried out by SPSS 21. Both Origin 9 and Surfer 11 were applied for the presentation of figures.

3 Results and discussion

3.1 Variations in physical and biogeochemical dataset

The box-whiskers plots of physical and biogeochemical parameters of the two study areas were visualized in Fig. 2. Accordingly, WT showed strong seasonal variations in both HZB and XSB due to the enhanced solar radiation in warm time. Average values were significantly higher (1.5 folds) in summer than those in spring (\(P<0.001\)). Salinity in XSB did not differ markedly during study intervals while significant difference (\(P<0.001\)) was observed in HZB. This could be attributed to the large freshwater influxes from QTR and the southward-flowing branch of CDW emptying into the bay in flooding season that strongly affected the seasonal pattern of salinity in HZB. By contrast, Tr marked higher in spring than it was in summer in XSB (\(P<0.001\)), probably owing to the affluent runoff carrying large amounts of suspended particulate matter (SPM) flowing into the
Fig. 2.
bay, whereas the seasonal differences were not detected in the vertically well mixed and turbid HZB (Milliman et al., 1985).

During the two cruises, DO varied substantially across the two bays \( (P<0.001) \). Lower DO in summer (apart from the effect caused by the rising water temperature) usually implied higher organic pollution as it was mainly consumed by the decomposition of organic matters (Kim et al., 2015). As a result, concentrations of COD and TOC in HZB were generally higher in summer while Chl \( a \) contents were relatively lower, since phytoplankton growth was constrained by light condition where high level SPM attached with particle organic matter prevailed in HZB due to the sediment resuspension (Liu et al., 2001). In contrast, concentrations of organic pollutants were lower in XSB while values of Chl \( a \) and pH in spring were considerably higher than that in summer \( (P<0.001) \). The increasing level of pH mainly attributed to the photosynthetic activity which reduced dissolved carbon dioxide (CO\(_2\)) in the water column (Shanthi et al., 2015). These findings demonstrated that there were significant temporal differences between the two bays in terms of biogeochemical factors.

Nutrient concentrations were generally higher in summer than that in spring, which could be ascribed to strong terrestrial contributions via riverine transports (Gao et al., 1993). The mean value of nutrients in HZB \( ((1.337\pm0.350) \text{ mg/L in spring and (1.514}\pm0.312) \text{ mg/L in summer of DIN}; \( (0.052\pm0.019) \text{ mg/L in spring and (0.067}\pm0.011) \text{ mg/L in summer of DIP}; \( (1.979\pm0.559) \text{ mg/L in spring and (2.018}\pm0.252) \text{ mg/L in summer of DSI, respectively}) \) \( (P<0.001) \). By contrast, concentrations of DSI in HZB, TP and DIN in XSB did not show noticeable seasonal variations, respectively \( (P>0.05) \). These results revealed severe eutrophication in northern Zhejiang coast according to Camargo and Alonso (2006). Ratios of N/P in the two bays were higher, with the average values of 66 and 52.6 in HZB and XSB, respectively, in spring compared with 55.5 and 38.7 in summer, respectively, exceeding the Redfield ratio (16:1) by 2.4–4 folds. The Si/N ratios were generally similar and did not show remarkable differences during the study periods \( (P>0.05) \). As the above-mentioned, HZB and XSB were all dominated by phosphate limitation (Justic et al., 1995), of which the degree in summer was more serious than that in spring.

Fig. 2. Box-whiskers plots of physical and biogeochemical parameters in HZB and XSB. HZB-spr represents spring in HZB, HZB-sum summer in HZB, XSB-spr spring in XSB, and XSB-sum summer in XSB. See abbreviations in Section 2.2.
ton communities. Hence, in the present study we believe that residence time was too low to shape autochthonous phytoplankton. Belgium was imported from the riverine tributaries because the most (the turbidity maxima area) reaches of the Schelde Estuary, Muylaert et al. (2000) reported that phytoplankton in the upper-part, indicating a significant hydrological pattern. High Chl \(a\) concentration was found in the turbid upper reaches, especially in Site 2 (28.2 μg/L) and Site 3 (28.7 μg/L). However, as presented by Tr values in the two groups, photosynthesis of phytoplankton was significant higher than Group 2 (\(P<0.001\)) because of the influence of thermal discharges of two coastal power plants (Guohua and Wushashan power plants) in the inner part of XSB (Fig. 6). The appropriate rise in water temperature could favor phytoplankton growth (Li et al., 2014; Sin and Jeong, 2015), which, to some extent, elevated Chl \(a\) level in Group 1. Moreover, the fish farming and other forms of mariculture activities in the area of Group 1 resulted in high levels of soluble nutrients (mean values of DIP, DIN, and DSi were 0.050 mg/L, 0.846 mg/L, and 1.182 mg/L, respectively, in the two areas (Fig. 4a). Figure 3b indicated that DIP and salinity were negatively correlated when salinity was below 16, while the positive correlation occurred when salinity was above 16. The result corresponded with the spatial distribution of surface salinity and water temperature (Figs 4c and d). Consequently, the other probable source might relate to the intrusion of external water masses characterized with high salinity and low water temperature during wet season (Wang et al., 2003, 2014; Ye et al., 2015), other than terrestrial inputs. XSB was also classified into two groups (Fig. 5). Stations 1–14 constituted Group 1, whereas Group 2 was shaped by Stas 15–34. The most distinct differences were identified in WT, Chl \(a\), DO, TOC, DIP, and DIN (Table 1). Water temperature in Group 1 was significant higher than Group 2 (\(P<0.001\)) because of the influence of thermal discharges of two coastal power plants (Guohua and Wushashan power plants) in the inner part of XSB (Fig. 6). The appropriate rise in water temperature could favor phytoplankton growth (Li et al., 2014; Sin and Jeong, 2015), which, to some extent, elevated Chl \(a\) level in Group 1. Moreover, the fish farming and other forms of mariculture activities in the area of Group 1 resulted in high levels of soluble nutrients (mean values of DIP, DIN, and DSi were 0.050 mg/L, 0.846 mg/L, and 1.182 mg/L, respectively, in the two areas (Fig. 4a). Figure 3b indicated that DIP and salinity were negatively correlated when salinity was below 16, while the positive correlation occurred when salinity was above 16. The result corresponded with the spatial distribution of surface salinity and water temperature (Figs 4c and d). Consequently, the other probable source might relate to the intrusion of external water masses characterized with high salinity and low water temperature during wet season (Wang et al., 2003, 2014; Ye et al., 2015), other than terrestrial inputs.

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### Table 1. Values of mean±standard deviation in each group of the two bays

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT/°C</td>
<td>25.10±1.11</td>
<td>24.62±1.41</td>
<td>25.02±0.41</td>
<td>22.80±0.64</td>
</tr>
<tr>
<td>Sal</td>
<td>7.95±2.74</td>
<td>15.95±3.47</td>
<td>24.58±0.40</td>
<td>26.22±0.59</td>
</tr>
<tr>
<td>Tr/m</td>
<td>0.4±0.1</td>
<td>0.3±0.3</td>
<td>1.3±0.1</td>
<td>1.8±0.9</td>
</tr>
<tr>
<td>pH</td>
<td>7.98±0.03</td>
<td>8.01±0.03</td>
<td>8.05±0.02</td>
<td>8.03±0.02</td>
</tr>
<tr>
<td>Chl (a)/μg·L(^{-1})</td>
<td>9.9±8.6</td>
<td>4.7±3.4</td>
<td>7.2±2.6</td>
<td>5.3±2.8</td>
</tr>
<tr>
<td>DO/mg·L(^{-1})</td>
<td>7.99±0.30</td>
<td>7.62±0.33</td>
<td>6.89±0.21</td>
<td>7.62±0.32</td>
</tr>
<tr>
<td>COD/mg·L(^{-1})</td>
<td>1.20±0.18</td>
<td>1.08±0.18</td>
<td>0.92±0.08</td>
<td>0.79±0.08</td>
</tr>
<tr>
<td>TOC/mg·L(^{-1})</td>
<td>2.35±0.30</td>
<td>1.85±0.19</td>
<td>1.82±0.14</td>
<td>1.42±0.10</td>
</tr>
<tr>
<td>TP/mg·L(^{-1})</td>
<td>0.247±0.058</td>
<td>0.305±0.113</td>
<td>0.091±0.011</td>
<td>0.08±0.033</td>
</tr>
<tr>
<td>TN/mg·L(^{-1})</td>
<td>1.995±0.201</td>
<td>1.682±0.216</td>
<td>1.005±0.013</td>
<td>0.902±0.063</td>
</tr>
<tr>
<td>DIP/mg·L(^{-1})</td>
<td>0.051±0.011</td>
<td>0.086±0.005</td>
<td>0.059±0.009</td>
<td>0.057±0.004</td>
</tr>
<tr>
<td>DIN/mg·L(^{-1})</td>
<td>1.714±0.175</td>
<td>1.253±0.201</td>
<td>0.846±0.068</td>
<td>0.769±0.088</td>
</tr>
<tr>
<td>DSi/mg·L(^{-1})</td>
<td>2.319±0.339</td>
<td>1.786±0.123</td>
<td>1.182±0.089</td>
<td>1.128±0.083</td>
</tr>
</tbody>
</table>

**Fig. 3.** Dendrogram of the sites in HZB.

### 3.2 Hierarchical cluster analysis

Values of mean±standard deviation were calculated to compare the differences between identified groups (Table 1). HCA divided HZB into two groups (Fig. 3). The first group consisted of 18 sampling sites, the inner part of the bay (Sites 1–16) and two sites (Sites 17 and 19) in the central part. The second group comprised of all the central and outer areas (Sites 18, 20–46). The mean values of Chl \(a\), TOC, TN, DIN, and DSi in Group 1 were higher than that in Group 2 which exhibited higher salinity, TP, and DIP concentrations than the first group. A sharp gradient in salinity (Fig. 3c) was observed between the two groups due to the strong dilution effect of freshwater in the inner part, indicating a significant hydrological pattern. High Chl \(a\) concentration was found in the turbid upper reaches, especially in Site 2 (28.2 μg/L) and Site 3 (28.7 μg/L). However, as presented by Tr values in the two groups, photosynthesis of phytoplankton in the whole HZB was obviously light-limited, suggesting the insignificant impact of biological removal (Gao et al., 1993). So how could the biomass be accumulated in such a turbulent area? Muylaert et al. (2000) reported that phytoplankton in the uppermost (the turbidity maxima area) reaches of the Schelde Estuary, Belgium was imported from the riverine tributaries because the residence time was too low to shape autochthonous phytoplankton communities. Hence, in the present study we believe that phytoplankton in the upper reaches of HZB was delivered from freshwater origin. These findings generally inferred that the environment of inner zone was strongly influenced by inland runoff. Given the high level of urbanization and industrialization in the Great Hangzhou City Area (GHCA), sites in Group 1 suffered from both point and non-point pollution, such as domestic sewage, industrial effluents, and agricultural wastewater. In comparison, sites in Group 2 might receive different sources of phosphorus. One possible source might be the direct discharges from coastal chemical industrial plants in both the northern (Jinshan Chemical Park, Shanghai) and southern (Zhenghai Petrochemical Park, Ningbo) sides, since phosphorus compounds were important raw materials of chemical industries. As a result, average value of DIP reached 0.053 mg/L and 0.060 mg/L respectively, in the two areas (Fig. 4a). Figure 3b indicated that DIP and salinity were negatively correlated when salinity was below 16, while the positive correlation occurred when salinity was above 16. The result corresponded with the spatial distribution of surface salinity and water temperature (Figs 4c and d). Consequently, the other probable source might relate to the intrusion of external water masses characterized with high salinity and low water temperature during wet season (Wang et al., 2003, 2014; Ye et al., 2015), other than terrestrial inputs.
leading to the deterioration of water quality (Fan and Jin, 1989; Jiang et al., 2013). While in Group 2, most sites were located in the more open waters, which functioned as the major waterway in XSB. The relative unstable environment made contaminants more easily spread out over the water column.

### 3.3 Principal component analysis

Results of PCA explained 71.56% of the total variance and yielded three principal components (PCs) in HZB (Table 2). PC1 accounted for 45.23% of the total variance with strong positive loadings on TN, DIN, and TOC, moderate loading on COD, and strong negative loading on salinity. The strong negative relationship between PC1 and salinity revealed that freshwater discharges from terrestrial runoff posed a huge impact upon HZB. Significant positive loadings of these variables could be indicative of nutrient and organic pollutions due to the ongoing developments of anthropogenic activities around HZB, which have resulted in tremendous effluents over the past two decades (Jia et al., 2014). The majority sources of these pollutants stemmed from domestic wastewater, industrial effluxes, and agricultural fertilizers influxes. Consequently, PC1 represented nitrogenous nutrient and organic pollutions. PC2 described 18.27% of the variance in the dataset and was highly correlated with WT, DO, TP, and DIP. The inverse relationship between WT and DO reflected the natural process of seasonal alternation because warmer water could cause a decrease in oxygen solubility, and thus, the less DO concentrations (Shrestha and Kazama, 2007). The strong positive loadings of TP and DIP demonstrated that the bay received severe phosphorus-containing contaminants, mainly derived from domestic sewage. Besides, considering the large complexes of high-tech chemical parks and petrochemical industries alongside the bay, other pollution source might come from industrial chemical effluents because phosphorous chemicals, like the metal phosphates, were used as industrial coatings to resist rust on the surfaces (Gazzaz et al., 2012). Unfortunately, we were not able to obtain heavy metal dataset, to further testify our results. Thus, PC2 stood for seasonal effect and phosphorous pollution. The third PC (8.06%) had strong positive loading on DSi and negative loading on Tr, respectively. DSi in the coastal waters primarily came from the soil weathering and the subsequent runoff via rainfall and river-flow (Kannel et al., 2008). The highly negative relationship between Tr and PC3 could further support it be-
cause of the elevated contents of SPM would reduce the transparency in the water column. Therefore, PC3 stood for natural process.

As for the XSB, four PCs were extracted, explaining 72.62% of the total variance (Table 2). PC1 demonstrated around 25.26% of the variance and received high loadings from WT, salinity, COD, and DIP. Similar to PC1 in HZB, significant negative loading of salinity on this PC also manifested the substantial impact of land-sourced inputs on the bay. Meanwhile, COD and DIP might relate essentially to human-induced point sources, like domestic wastes and urban wastewater plants, which contained large amounts of organic compounds, detergents, and inorganic salts. Hence, PC1 mainly represented domestic wastes. PC2 explained 20.77% of the variance. It exhibited strong loadings on TOC, TP, TN and DIN, suggesting influence from nutrient and organic pollutions. Taking into account the considerable scale of mariculture industry in XSB (12,366 hm$^2$ in 2013) (OFAZP, 2014), the farming feeds should, to a large degree, be responsible for the diffusion of nutrients and organic matters. In addition, this type of non-point pollution source has been studied worldwide. For example, Jiang et al. (2013) reported that excessive aquaculture activities considerably contributed to the high eutrophic level of XSB. Herbeck et al. (2013) discovered high amounts of aquaculture effluents rich in dissolved inorganic and organic matter released from shrimp and fish ponds caused great eutrophic conditions in northeastern coast of Hainan. Thomas et al. (2010) revealed huge net loads of nitrogen exported from shrimp farm in the New Caledonia lagoon. So this PC could be interpreted as aquaculture pollution. PC3 (14.85%) and PC4 (11.74%) were characterized by WT, pH, and Chl$\alpha$; Tr and DO, respectively, which documented biological activities. High transparency and warm water temperature favored the photosynthesis of phytoplankton, leading to the decrease in CO$_2$, and the increase in both DO and pH values in the water column, and finally the high biomass.

Overall, six potential pollution sources were identified in the two bays (Table 3). The pollution sources of HZB derived primarily from the terrestrial runoff in the upper side as well as coastal

![Fig. 6. Spatial distribution of surface water temperature (°C) in XSB.](image)

### Table 2. Loadings of the 13 variables in each principal component for HZB and XSB

<table>
<thead>
<tr>
<th>Variables</th>
<th>HZB</th>
<th>XSB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PC1</td>
<td>PC2</td>
</tr>
<tr>
<td>WT</td>
<td>0.295</td>
<td>-0.823</td>
</tr>
<tr>
<td>Sal</td>
<td>-0.917</td>
<td>0.176</td>
</tr>
<tr>
<td>Tr</td>
<td>-0.114</td>
<td>0.318</td>
</tr>
<tr>
<td>pH</td>
<td>-0.620</td>
<td>0.176</td>
</tr>
<tr>
<td>Chl$\alpha$</td>
<td>0.499</td>
<td>0.248</td>
</tr>
<tr>
<td>DO</td>
<td>0.169</td>
<td><strong>0.769</strong></td>
</tr>
<tr>
<td>COD</td>
<td>0.624</td>
<td>0.141</td>
</tr>
<tr>
<td>TOC</td>
<td><strong>0.872</strong></td>
<td>0.326</td>
</tr>
<tr>
<td>TP</td>
<td>0.008</td>
<td><strong>0.735</strong></td>
</tr>
<tr>
<td>TN</td>
<td><strong>0.919</strong></td>
<td>-0.093</td>
</tr>
<tr>
<td>DIP</td>
<td>0.043</td>
<td><strong>0.830</strong></td>
</tr>
<tr>
<td>DIN</td>
<td><strong>0.885</strong></td>
<td>-0.029</td>
</tr>
<tr>
<td>DSi</td>
<td>0.223</td>
<td>0.089</td>
</tr>
<tr>
<td>Variance/%</td>
<td>45.23</td>
<td>18.27</td>
</tr>
<tr>
<td>Cumulative/%</td>
<td>45.23</td>
<td>63.50</td>
</tr>
</tbody>
</table>

Note: Values in bold highlighted controlling factors.

### Table 3. Identification of potential pollution sources in HZB and XSB

<table>
<thead>
<tr>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZB</td>
<td>nitrogenous nutrient and organic pollutions</td>
<td>seasonal effect and phosphorous nutrient pollutions</td>
<td>natural process</td>
</tr>
<tr>
<td>XSB</td>
<td>domestic wastes</td>
<td>aquaculture pollution</td>
<td>biological activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>biological activities</td>
<td></td>
</tr>
</tbody>
</table>
industrial and agricultural influxes. While in XSB, domestic sewage and mariculture industries were the main pollution sources. Hence, it is of overarching significance to continue to implement the routine-monitoring project for terrestrial pollutants fluxes into marine environment and enhance the law enforcement on illegal discharge as well as raising the standard of wastewater treatment in the two bays. Furthermore, greater attention should be paid on the scientific management of aquaculture industries and their rational layout in XSB.

4 Conclusions

In the present study, two cruises of physical and biogeochemical investigations were conducted in HZB and XSB. Results indicated that physical and biogeochemical parameters in the two bays exhibited significant temporal and spatial differences. HCA divided both HZB and XSB into two subareas based on the similarity of physical and biogeochemical properties. PCA identified three latent pollution sources for HZB, namely nitrogenous nutrient and organic pollutants, seasonal effect and phosphorous nutrient pollutants, and natural process. Meanwhile domestic sewage, aquaculture pollution as well as biological activities were the major pollution sources in XSB. These findings demonstrated that water quality of HZB and XSB were strongly affected by anthropogenic activities. Given the present status, proper measures such as the long-term monitoring networks, strict supervision over wastewater discharge, and scientific management upon coastal industries, etc. should be carried out immediately to protect the aquatic ecoinvironment of the two bays.

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