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A continuing 30-year decline in water quality of Jiaojiang Estuary, China

Chun-ye Wang [a,b], Bin Zhou [b,*], Bei Huang [c]

[a] College of Marine Science, Shanghai Ocean University, Shanghai 201306, PR China
[b] College of Science, Hangzhou Normal University, Hangzhou 311121, PR China
[c] Zhejiang Provincial Zhoushan Ocean Ecological Environment Monitoring Station, Zhoushan 316000, PR China

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Abstract

A quantitative description of a long-term series of aquatic environmental factors and their spatial distributions was generated using measured data from the Jiaojiang Estuary from 1982 to 2011. The aquatic environmental factors included suspended matter, salinity, and nutrients. Based on these factors, the aquatic ecosystem health in the Jiaojiang Estuary over the last 30 years was analyzed. The results indicated that the suspended matter concentration in the estuary was mainly affected by the amounts of suspended sediment and solid waste, with the value fluctuating over a long period, and the range of high concentration expanded continually; the salinity was mainly affected by precipitation and surface water resources, showing an overall decreasing trend, and the region with low salinity moved seaward and toward the reclamation areas; and the nutritional status, mainly affected by discharge of industrial wastewater and domestic sewage, was satisfactory in the 1980s and 1990s, but the status became severe in recent years. Reclamation had a great influence on these three factors: high reclamation strength led to a significant increase in the suspended matter concentration and a deterioration of the nutritional status, and the reclamation rate was negatively related with the salinity in the estuary. There was a significant positive correlation between the health status of the aquatic ecosystem and salinity, with a correlation coefficient of 0.93. The correlation coefficient between the health status and nutritional status was −0.71, while the correlation between the suspended matter concentration and health status was not as significant as that of the other two factors. The dynamics of the aquatic environment could be divided into four stages: sustainable health from the 1980s to the 1990s, continued deterioration from 2000 to 2003, improvement from 2004 to 2005, and secondary deterioration from 2006 to 2011. The Jiaojiang Estuary is faced with imminent environmental pressure at present.

Keywords: Water quality decline; Aquatic ecosystem health; Aquatic environmental factor; Suspended matter concentration; Salinity; Nutritional status; Jiaojiang Estuary

1. Introduction

With the acceleration of economic development and human activities, the destruction of the integrity of water sources has become more serious, requiring intervention (Steinemann, 2000; Dante et al., 2005; Yang et al., 2007). An estuary is the ecological convergence zone of freshwater and marine systems, which exhibits unique physical, chemical, and biological properties and high productivity.

Similar to many estuaries worldwide, the watershed upstream of the Jiaojiang Estuary is characterized by a high population density and developed social economy. The critical water environmental problems in this area result from the discharge of industrial wastewater and domestic sewage from numerous outfalls into the adjacent waters. Industrial effluent has been discharged into local water bodies and has further entered the Jiaojiang Estuary, leading to water quality deterioration. Tide cycles have further caused the widespread death

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* Corresponding author.
E-mail address: hznu_bzhou@126.com (Bin Zhou).
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of shellfish in offshore aquaculture (Wang et al., 2005). Moreover, human activities have altered the natural conditions and created significant pressure on the aquatic environment in the Jiaojiang Estuary.

Research on the aquatic ecosystem of the Jiaojiang Estuary by Du et al. (2011) has indicated that the water quality of this area was worse than Grade IV according to the *Sea Water Quality Standard* (GB 3097-1997), and runoff and pollutant emissions were the main factors leading to the water quality deterioration. Zhang et al. (2013) showed that dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP), and oil were the primary substances, exceeding their control standards in the Jiaojiang Estuary. Jiang et al. (2006) surveyed the concentrations of typical organic contaminants, indicating that wastewater from the chemical industry was the main source of aniline and nitrobenzene in seawater and sediment. PAHs were found from the combustion of fossil fuels at the Taizhou Power Plant, and PCBs from the translocation of waste emission from the waste electronic machine recycling industry. Based on an investigation of the concentrations of DIN, DIP, Hg, Pb, dissolved oxygen (DO), and chemical oxygen demand (COD) in the Jiaojiang Estuary, Wang et al. (2005) concluded that the estuary was in a state of serious pollution. The average eutrophication index there was very high, with a value reaching 288, and the biodiversity and biomass of the system were quite low, demonstrating the frangibility of the Jiaojiang Estuary.

Guo and Chen (2007) demonstrated that sedimentation at harbors is an emergent problem for some coastal cities in this area. These researchers obtained distribution characteristics of suspended matter in the Jiaojiang Estuary and Taizhou Gulf, and found that the oil concentration was high in the Jiaojiang Estuary, and that the water quality at 83.40% of the stations was worse than Grade I. Li et al. (1999) showed that suspended matter (SM) mainly included suspended sediment, inorganic and organic materials, and clay, which are water-insoluble, and the suspended sediment mainly came from sea transport. Because of the reduction of sea transport in recent years, the suspended sediment concentration in the Jiaojiang Estuary has decreased.

Some contaminants come from ocean engineering projects, such as land reclamation. The Jiaojiang Estuary reclamation has a long history, which can be dated back to the year 1145. By 1949, an area of 307 km^2 had been reclaimed, with seven seawalls constructed on the south bank of the estuary. After that, the Jiaojiang Estuary underwent additional reclamation projects, and the seawall number increased to 10. From 2000 to 2013, the number of seawalls increased to 12, with two other seawalls constructed in 2001 and 2009, respectively. At present, the total area of reclamation has reached about 450 km^2.

Although investigations of the water quality have been conducted in the Jiaojiang Estuary, this research was focused either on singular aquatic environmental factors or aquatic organisms. Results that profiled the aquatic environmental quality more holistically were ephemeral and covered only one season or one year. The dynamics of the aquatic environment over long periods of time need to be analyzed more completely, especially for parameters regarding industrial wastewater, domestic sewage, hydrodynamics, and so on.

For the purpose of identifying the reasons for the water quality decline in the Jiaojiang Estuary, the aquatic environmental factors and the aquatic ecosystem health over the last 30 years were analyzed based on the historical data. Natural and human factors were also explored. It is expected that this study will provide theoretical support to environmental protection in the Jiaojiang Estuary.

2. Methodology

2.1. Study area

The Jiaojiang Watershed encompasses an area of 6 603 km^2. Approximately 0.53 million people lived there in 2013. It is located on the central coast of Zhejiang Province, at the confluence of the Lingjiang and Yongningjiang rivers. The coastline is 51.4 km. The area is mainly covered with water, with land predominantly in agriculture and construction. The average runoff is 163 m^3/s, the annual river discharge is 6.6 km^3, and the rainy season is from April to September.

The Jiaojiang Estuary is located in the middle of Zhejiang Province, which opens outward like the mouth of a horn. The depth of most of the area is less than 10 m, and there are shallow regions with a depth less than 2 m outside the mouth (Guo and Chen, 2007). The average tidal range in the Jiaojiang Estuary is 4.01 m, and the maximum tidal range is 6.30 m. With abundant natural resources, the economic development is rapid in this region. Marine aquaculture has been developed in this region, and fish, shrimp, and crab farms have been established (Sun et al., 2012). Industrial development is quite intense on both banks of the Jiaojiang River, and construction and operation have greatly threatened the adjacent intertidal and coastal waters (Zhao et al., 2009).

2.2. Station setting

Water samples were collected in summer, and the sampling range was 28°37′N to 28°41′N and 121°26′E to 121°37′E. This study was only concerned with coastal waters in the Jiaojiang Estuary, and five marine ecological monitoring stations were set along the river-to-sea direction, denoted as S0, S1, S2, S3, and S4 in Fig. 1.

2.3. Data collecting methods

The sample collection, pretreatment, and analysis were conducted according to the procedures described in *Specifications for Marine Monitoring* (GB17378.3-1998 and GB17378.4-1998). The reclamation dynamics in the Jiaojiang Estuary were extracted using remote sensing images on the ArcGIS platform based on color, shade, size, shape, texture, pattern, location, and other combinations. The concentrations of suspended matter, salinity, DO, COD, active phosphate (PO_4^{3-}), DIN, and oil were obtained from the investigation by the Zhejiang Provincial Zhoushan Ocean Ecological