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Original Articles

Linking water quality with the total pollutant load control management for nitrogen in Jiaozhou Bay, China

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ABSTRACT

Eutrophication was once the most serious problem for the overload of nitrogen in Jiaozhou Bay, with the development of society and the economy of Qingdao, China. Total pollutant load control management (TPLCM) was applied for 10 years via two five-year plans since 2006 in Qingdao, China, and it was further strengthened after 2011. To evaluate the effect of TPLCM on the water quality of Jiaozhou Bay, dissolved inorganic nitrogen (DIN) was chosen as the water quality factor in response to the land-based load of total dissolved nitrogen (TDN), ammonia nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) during 2001–2015. Special attention was given to temporal and spatial changes. The flux of land-based TDN obviously decreased during the period of the '11th Five-Year Plan (2001–2010)' of China, with an approximate 17% annual reduction rate, which caused the annual mean concentration of DIN to significantly decrease in Jiaozhou Bay. The water quality did not significantly improve in the period of the '12th Five-Year Plan (2011–2015)' of China in Jiaozhou Bay. There was little reduction of NO_3-N, which was the predominant nitrogen form, although the reduction of NH_4-N did occur. The TPLCM in the Dagu River and the Haibo River watershed has occurred since 2000, and it had a considerable reduction in land-based TDN. The seawater quality improved at the northwest and south parts of Jiaozhou Bay. The TPLCM was prompted by insufficient progress in the Lichun River and the Moshui River watershed, and there was continued poor water quality in the north and northeast areas of Jiaozhou Bay from 2001 to 2015. The next phase of the TPLCM should promote land and marine development in a coordinated way, with more attention devoted towards the control of non-point sources, the introduction of advanced sewage treatment and coastal restoration.

1. Introduction

Eutrophication is a widespread problem in coastal oceans, caused by the overload of nutrients (Boynton et al., 1995; Carpenter et al., 1998; Flemer and Champ, 2006), and it is a serious threat to the integrity of coastal ecosystems (NRC, 1993, 1994). Nitrogen is the primary cause of eutrophication in many coastal ecosystems, which influences the biological component, species diversity and activity (Howarth and Marino, 2006). Compared to the pre-industrial condition, nitrogen loading to the global coastal and marine waters has doubled due to anthropogenic activities. These activities were estimated to be responsible for approximately 60% of the global export of dissolved inorganic nitrogen (DIN), and they significantly increased the dissolved organic nitrogen (DON) export in many regions (Green et al., 2004; Dumont et al., 2005; Harrison et al., 2005; Seitzinger and Lee, 2016). If measures are not taken, serious problems will occur, such as the restriction of the sustainable development of society and harming the growth of human beings over the long-term (Driscoll et al., 2003). The research on the emission abatement of nitrogen is an urgent problem, which will provide a theoretical basis on the temporary and spatial variabilities of the water quality in coastal and marine ecosystems.

Jiaozhou Bay is located on the northeast coast of China (35°58′–36°18′N, 120°04′–120°23′E). More than 10 rivers, including the Haibo, Licun, Moshui and Dagu rivers, and wastewater treatment plant (WWTP) sites (Licun and Haibo) account for approximately 75% of the recent total freshwater inflow (Liu et al., 2005; Li et al., 2015a). Dagu

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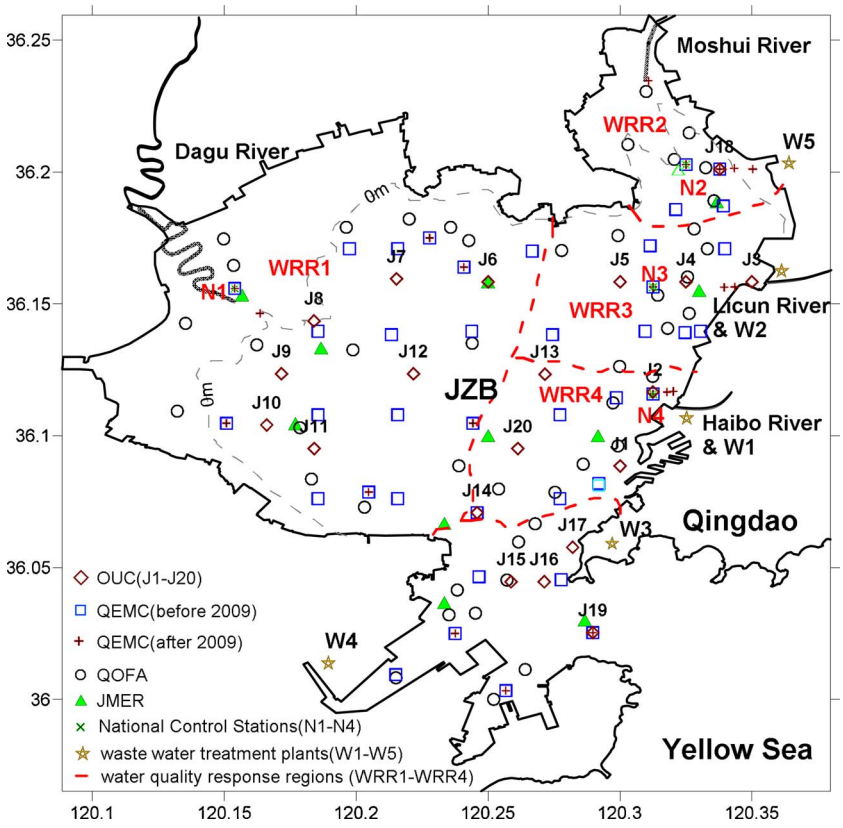

Fig. 1. Map of Jiaozhou Bay (JZB) showing the survey stations for Qingdao Environmental Monitoring Center (QEMC), including National Control Stations (N1-N4), Qingdao municipal Ocean and Fisheries Administration (QOFA), the Jiaozhou Bay Marine Ecosystem Research station (JMER), and Ocean University of China (OUC), Dagu River, Moshui River, Licun River, Haibo River, and the wastewater treatment plants (WWTPs) in Haibo (W1, since 1993), Licun (W2, since 1997), Tuandao (W3, since 1998) Lianwan (W4, since 2004) and Loushan (W5, since 2008), and the water quality response regions of the Dagu River (WRR2), Moshui River (WRR2), Licun River and Licun WWTP (WRR3), and the Haibo River and Haibo WWTP (WRR4).

River is the largest, with a watershed area of 6131.3 km^2, followed by Moshui River (watershed area 317.2 km^2), Licun River (watershed area 52.30 km^2) and Haibo River (watershed area 27 km^2). Jiaozhou Bay is a semi-enclosed coastal embayment, with a surface area of approximately 374 km^2, an average depth of approximately 7 m, and an average rainfall of 725 mm to 1100 mm. The bay is surrounded by Qingdao, which is located in the southern coastal area of the Shandong Peninsula, China (Fig. 1). Most of the land-based pollutants of Qingdao drain into the bay (Wang et al., 2006). Since the beginning of the 1980′s, with the rapid development of the social economy, the problem of water quality in Jiaozhou Bay has become more serious, and eutrophication is the most serious problem from the overload of nitrogen in Jiaozhou Bay (Shen, 2001; Shen et al., 2006; Liu et al., 2005). Previous studies showed that the load of terrigenous total nitrogen increased over the years, and the concentration of DIN has been increasing in Jiaozhou Bay (Sun et al., 2011; Sun and Sun, 2011; Zhang et al., 2017). Rivers play a fundamental role in the transport of nutrients from land to sea (Seitzinger and Harrison, 2008; Seitzinger and Lee, 2016). Based on long-term data, the terrigenous total nitrogen load was identified one of the key control indicators responsible for the variation of the concentration of DIN in Jiaozhou Bay (Zhang et al., 2017).

Total pollutant load control management (TPLCM) was applied for 10 years via two five-year plans since 2006 in Qingdao (namely, the National ‘11th Five-Year Plan’ and the National ‘12th Five-Year Plan’), which targeted the total emissions of pollutants. The main purpose of the TPLCM was divided into two stages: 1) the reduction of chemical oxygen demand (COD) by 10% during the year from 2006 to 2010; and 2) the reduction of ammonia by 10% during the year from 2011 to 2015. Numerous management measures were also implemented by the Qingdao municipal government since the mid-2000s, such as industrial enterprises relocation, improving the treatment capacity of WWTP, stream and watershed restoration, building dams in rivers, giving up coastal shrimp pond and shoreline management (Zhang, 2007; Jiang et al., 2011). Currently, the Marine Environmental Quality Bulletin of Qingdao showed that nitrogen pollution is still serious in Jiaozhou Bay (QOFA, 2016). According to the Total Quality Control of Pollutants Discharged into the Sea Programme, the seawater qualities in Quanzhou Bay were improved by 2012 (Zhao et al., 2015). However, a long period of total maximum daily load and the extensive restoration efforts have not yet improved the water quality in the Chesapeake Bay, U.S.A. (Linker et al., 2013). The European Commission introduced the Marine Strategy Framework Directive (MSFD, 2008/56/EC), which aimed at achieving a good environmental status in European marine waters by 2020. The MSFD evolved tremendously over the last decade and was recently assessed (Romero et al., 2013; Martínez-Gómez et al., 2017; Markogianni et al., 2017). In order to analyse the influence on water quality and assess the effect of TPLCM in Jiaozhou Bay, it is necessary to take into account surveys and literature data. It is not only the objective demand of the current water quality improvement in the bay, but it will also provide a scientific basis for the reduction of nitrogen pollutants in Jiaozhou Bay.

This paper assessed the effect of TPLCM on the water quality in Jiaozhou Bay based on the data of the distribution of nitrogen and land-based nitrogen load in 2001–2015, normalized by the kriging interpolation method and river runoff correcting. The main objectives of this study were to: 1) provide an overview of the concentration of DIN in the bay and land-based nitrogen loads around Jiaozhou Bay during 2001–2015, with a special emphasis on temporary and spatial variabilities; and 2) evaluate the effect of TPLCM on water quality and determine the relationship among the land-based nitrogen loads and the concentration of DIN in the bay.

2. Materials and methods

2.1. Data

2.1.1. Sources

DIN concentration data in Jiaozhou Bay used in the present study were obtained from several authorities and by monitoring. We compiled the most recent information available from four different sources: