Ecological Indicators 67 (2016) 673–683

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Short Communication

Quantitative analysis of anthropogenic influences on coastal water – A new perspective

Minggang Cai[a,b,*,1], Yan Liu[c,1], Kai Chen[a], Dongren Huang[d], Shengyun Yang[b]

[a] Coastal and Ocean Management Institute, Xiamen University, Xiamen 361102, China
[b] College of Ocean and Earth Sciences, Xiamen University, Xiamen 361102, China
[c] Department of Finance, Ocean University of China, Qingdao 266100, China
[d] Monitoring Center of Marine Environment and Fishery Resource, Fujian Province, Fuzhou 350003, China

ARTICLE INFO

Article history:
Received 13 December 2015
Received in revised form 6 February 2016
Accepted 17 March 2016
Available online 25 April 2016

Keywords:
Long-term variation
Seawater quality
Quantitative methods
Coastal management
Interdisciplinary cooperation
Western Xiamen Bay

ABSTRACT

Coastal environment has been disturbed by human activities for a long time, especially in the rapidly urbanizing and industrializing areas. Although the surrounding area has achieved great economic success in the past 30 years, Western Xiamen Bay (China) is seriously affected by pollutants and is facing increasing ecological pressure. Because of this, Xiamen was selected in 1994 as a demonstration site for implementing an integrated coastal management program, which included a series of measures for protecting the coastal environment. However, coastal environment is dynamic, complex and site-specific, and thus a scientific quantitative evaluation framework is necessary for environment quality analysis and effective coastal management. In this study, we used oceanographic knowledge together with quantitative methods (Bai-Perron's structural break test) to analyze the long-term variations of water quality indices (pH, DO, COD, DIN, PO_4-P and Oil) in Western Xiamen Bay. In addition, we compared with other coastal areas to identify the effectiveness of phosphorus-based nutrient management measures and predicted the probable variation trend in the future. The results show that in Western Xiamen Bay: (1) the concentrations of DO and Oil in seawater are effectively controlled by local coastal management measures; (2) seawater acidification will continue to worsen based on the present situation; and (3) the P-limitation treatment strategies are effective and PO_4-P concentration starts to fall according to the multiple statistical analysis and Environmental Kuznets Curve. This paper hopes to provide an epitome of the conflicts and consolations between socioeconomic development and environmental quality in the past, and hints for coastal management in the future.

1. Introduction

Coastal zones play an important role in socioeconomic development; meantime they suffer increasing stress from human activities (Halpern et al., 2008; Tessler et al., 2015). About 60% of the world's people live within 100 km of the coastline (Vitousek et al., 1997a), and are highly dependent on all kinds of coastal ecosystem services (Millennium Ecosystem Assessment, 2005). Accordingly, human activities often generate negative effects on coastal ecosystem functioning, such as ocean acidification, eutrophication, habitat degradation, and even biodiversity loss (Cai et al., 2011; Chandra, 2011; Dietz et al., 2003; Orr et al., 2005; Waycott et al., 2009). Rapidly urbanizing and industrializing coastal areas face serious ecosystem pressure, especially those with relatively weak water circulation (Levin et al., 2009), reflected by lower pH and dissolved oxygen, high levels of nutrients and petroleum hydrocarbons in seawater (Cai et al., 2011; Veerasingam et al., 2011; Williams et al., 2010). Water is considered as the most poorly managed resource in the world (Lee et al., 2006; Usaquén Perilla et al., 2012), therefore, it is necessary to investigate the influence of human activities on water quality variation for effective coastal management.

Globally, a series of long-term monitoring programs has been implemented to evaluate the effect of human activities on the coastal environment (Chai et al., 2009; Liu et al., 2005; Ma et al., 2012a, 2012b, 2012c; Martin et al., 2013; Nishikawa et al., 2010; Raabe and Wiltshire, 2009; Rasheed et al., 2012; Taylor et al., 2010; Williams et al., 2010; Xu et al., 2011). These studies find strong correlations between human activities and environmental condition in the coastal areas For instance, in China, industrialized animal

* Corresponding author at: Coastal and Ocean Management Institute, Xiamen University, Xiamen 361102, China. Tel.: +86 592 288 6188.
E-mail address: mgcai@xmu.edu.cn (M. Cai).
[1] Joint first author.

http://dx.doi.org/10.1016/j.ecolind.2016.03.037
1470-160X/

production and artificial constructions, such as seawall, became major contributors to coastal environmental degradation (Cao et al., 2007; Ma et al., 2014). Since coastal environment is highly dynamic and complex (Chen and Hong, 2012), challenges exist in how to assess the responses of water quality, and the effectiveness of coastal management.

The assessment of human activities on coastal water quality has been studied over decades. Previous results tend toward a qualitative description since the ecological responses are generally non-linear (Taylor et al., 2010). Moreover, the selection of indices is often subjective (Rosenberg et al., 2004). With the increasing environmental concerns of the public, officials need much more quantitative analysis for decision-making. The seminal works of Grossman and Krueger (1995) show that, after controlling non-economic determinants of pollution, there is an inverted U-shaped relationship between measures of pollution concentrations and income per capita, which is regarded as the Environmental Kuznets Curve (EKC). For example, Paudel et al. (2005) investigated the EKC on water pollution with both semiparametric and parametric models using watershed level data for the state of Louisiana, USA. Another kind of quantitative environmental studies is sensitivity analysis, among which the most popular one is global sensitivity and uncertainty analyses (GSUA) (Saltelli et al., 2008). It emphasizes on studying uncertainties in input factors onto the model outputs of interest via a variance-based method by specifying the probability distribution functions (PDFs) of the inputs and the outputs. Unfortunately, GSUA is not quite suitable for studying the impact of human activities on coastal environment since the specification of PDFs is very complicated for socioeconomic indices. To summarize, after a thorough study of the previous literature, it is found that there is a strong need for a suitable quantitative framework combined interdisciplinary knowledge for assessing the effects of human activities on coastal waters.

With these concerns, we used data from Western Xiamen Bay (WXB), which has a relatively long-term monitoring record that is unusual in China. Xiamen was designated as one of the first four "special economic zones" in 1980, and Xiamen sea area was approved to establish national special marine protected area in 2011 (Ma et al., 2013). Xiamen has experienced an extensive urban expansion since the early 1980s, however, at the cost of coastal environmental degradation, especially eutrophication (Chen et al., 2013; Hong et al., 1999; Yang et al., 2012).

WXB as a study area is important for three reasons. First, over three million people live around WXB, where rapid population growth and intense human activities have led to a high level of pollutant emission. As more than 75% of the nutrients load from the surrounding area (Pan et al., 2011), it is therefore assumed that the water quality represents, to a degree, the general environmental quality situation in the whole of WXB. Secondly, WXB has experienced rapidly urbanizing and industrializing process since the 1980s. The urbanizing rate has risen consistently, from 40% in the early 1990s to 88.6% in 2012 (the data is from Xiamen Special Economic Zone Yearbooks). The land use changed greatly within the Xiamen coastal zone. For example, the area proportion of construction land was increased by 193.0%, while that of farmland and forestland was decreased by 55.2% and 41.4% from 1987 to 2011 (Huang et al., 2012). Thirdly, Xiamen has been selected as a demonstration site for the GEF/UNDP/IMO Regional Program for integrated coastal management (ICM) since 1994; and the environmental quality of WXB has also been the subject of extensive research and government efforts at rehabilitation (Peng et al., 2006). These reasons form the basis for our analysis of the relationship between water quality and human activities in the bay.

In this study, we attempted to use multiple statistical methods, to (1) analyze the long-term variation of water quality of WXB responses associated with human activities during the past three decades; (2) compare with other coastal areas to identify the effectiveness of coastal management measures; and (3) predict the possible water quality trend in the future. Through this case, we hope to not only improve the knowledge of the relationship between coastal water quality and human activities for researchers and city officials, but also update scientific information for future coastal management.

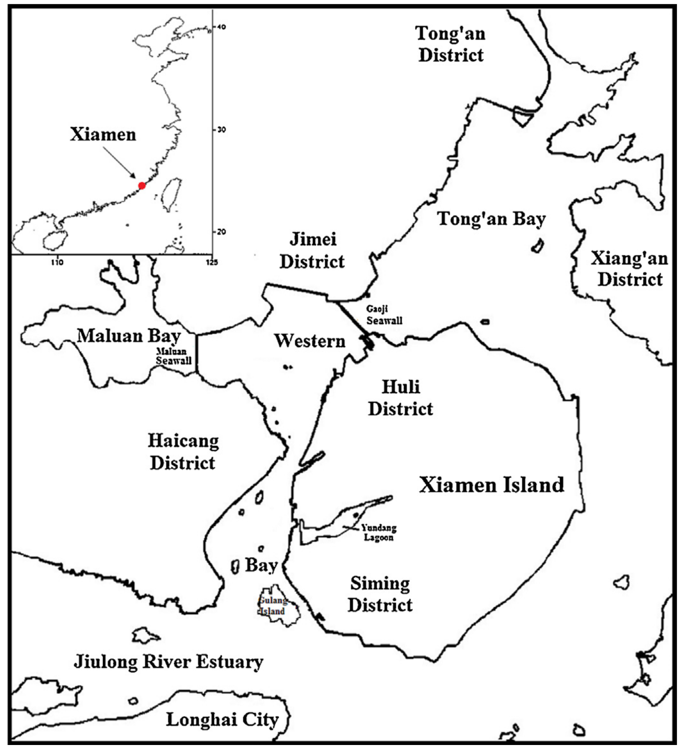

Fig. 1. Geographic location of Western Xiamen Bay.

2. Materials and methods

2.1. Study area

Western Xiamen Bay (24°29′N, 118°04′E) is a dumbbell-shaped semi-enclosed bay located at the western side of Xiamen Island (Fig. 1). The main basin of the bay has an area of 45.7 km^2 and the water depth ranges from 6 to 25 m with a deep-water coastline of about 30 km. This area is subjected to the influence of a subtropical oceanic monsoon climate with average annual precipitation of 1337.7 mm, and vulnerable to climate change in extreme events (e.g. typhoons and rainstorms) and seasonal oscillations (Ding and Wang, 2008). The bay is bordered on its northeastern side by the Gaoji Seawall and its northwestern side by the Maluan Seawall. The bay opens to the Jiulong River estuary to the south and is sheltered from currents and tides by several small islands.

Xiamen has experienced great socioeconomic and environmental changes during the past 30 years. In 1994, Xiamen was selected as a demonstration site of a 5-year ICM program to manage marine pollution. In the same year, Xiamen was granted local legislative power by The National People's Congress. Thereafter, a series of coastal management laws, policies and governance actions have been made and implemented, aimed at balancing multiple use conflicts and controlling pollution sources in WXB and adjacent areas (Table 1). In 2002, the government implemented another treatment program in WXB, through banning aquaculture and dredging the navigation channel to improve water quality and hydrodynamic conditions. In 2005, in order to address the