Estuarine, Coastal and Shelf Science 169 (2016) 85–94

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Agricultural water consumption decreasing nutrient burden at Bohai Sea, China

Yindong Tong [a, b, c, *], Xuejun Wang [b, d], Gengchong Zhen [e], Ying Li [f], Wei Zhang [e, **], Wei He [b, d]

[a] School of Environmental Science and Engineering, Tianjin University, Tianjin, 300072, China
[b] Ministry of Education Laboratory for Earth Surface Processes, Peking University, Beijing, 100871, China
[c] China-Australia Centre for Sustainable Urban Development, Tianjin, 300072, China
[d] College of Urban and Environmental Sciences, Peking University, Beijing, 100871, China
[e] School of Environment and Natural Resources, Renmin University of China, Beijing, 100872, China
[f] Department of Environmental Health, College of Public Health, East Tennessee State University, Johnson City, TN, 37614, USA

ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form
30 November 2015
Accepted 11 December 2015
Available online 13 December 2015

Keywords:
Agricultural water consumption
Huanghe river
Nutrient balance
Nutrient burden
Bohai sea

ABSTRACT

In this study, we discussed the impacts of human water consumption to the nutrient burden in a river estuary, and used Huanghe River as a case study. The agricultural water consumption from the Huanghe River has significantly decreased the natural water flows, and the amount of water consumption could be almost twice as high as the water entering into the estuary. According to our calculation, agricultural water usage decreased TN outflows by 6.5×10^4 Mg/year and TP outflows by 2.0×10^3 Mg/year. These account for 74% and 77% of the total output loads. It has been widely reported that the majority of the rivers in northern China were severely polluted by nutrients. Its implication on the budget of nutrient in the estuary ecosystem is not well characterized. Our study showed that the discharge of nutrients in the coast waters from polluted rivers was over concerned. Nutrients in the polluted rivers were transported back to the terrestrial systems when water was drawn for human water consumption. The magnitudes of changes in riverine nutrient discharges even exceed the water-sediment regulation trails in the Huanghe River. It has non-negligible impact on estimating the nutrient burden in costal water ecosystem.

1. Introduction

The transport of nutrients from the terrestrial systems to the coastal waters represents a key pathway in the global geochemical cycle (Walsh, 1991; Dai et al., 2011). Anthropogenic activities contribute more than natural process in the transport of nutrients into the seas. Rapid increases in nutrient sources and discharges have greatly changed the nutrient compositions and concentrations in the sea, causing the overabundance of nutrients in the estuarine environment (Mukhopadhyay et al., 2006; Richardson and Jørgensen, 2013; Gao and Wang, 2008; Hessen et al., 2010). This caused the sea water to be more turbid and frequent occurrences of harmful algal blooms (HABs) (Zhang et al., 1999; Wang, 2006). For instance, from 2006 to 2012, HABs occurred approximately 500 times in the coastal waters of China, mainly at the estuaries of large rivers, and an increasing trend of HABs occurrences was observed (China's State Oceanic Administration, 2012). When considering the negative impacts of human activities on the watersheds, a neglected fact is that, the massive human water consumption from the rivers could also decrease the nutrient burdens at the estuary. Although the negative effects of nutrient discharges to the offshore areas have been widely studied (Zhang et al., 1999; Zhang, 2008; Li et al., 2014), the potential positive effects of human activities have not been well understood. In the wet-climate areas such as Yangtze River Basin, the human water consumption from the river was relatively small. Hence, limited impacts would be imposed to the estuaries from human water consumption (Tong et al., 2015a). However, in the dry-climate areas, river is an important water source for agricultural and industrial usage, and the massive water consumption could decrease the water outflows and nutrient discharges into the estuary significantly.

The Huanghe River, originating from the Qinghai–Tibetan

* Corresponding author.
** Corresponding author.
E-mail addresses: yindongtong@tju.edu.cn (Y. Tong), zhw326@ruc.edu.cn (W. Zhang).

http://dx.doi.org/10.1016/j.ecss.2015.12.006
0272-7714/

Plateau at an elevation of 4500 m, is the second longest river in China. The river flows about 5464 km and drains an area of 75.2×10^4 km^2 before entering into the Bohai Sea, in northern China (Zhang et al., 2013). Most areas of the Huanghe River basin are located in the dry and water-deficient regions. In order to meet the water demand in this region, over 50% of the natural water flows in the Huanghe River was consumed for agricultural irrigation and industrial usage in the basin (Yellow River Conservancy Commission of MWR, 2008–2012). From 1950 s to the early 1990 s, the water consumption from the Huanghe River increased by three-fold (Chen et al., 2005; Wang et al., 2007). The amount of water consumption by human activities (~3×10^{10} m^3) was 1.7 times as the runoff being discharged into the Bohai Sea (~1.8×10^{10} m^3) (Kong et al., 2012; Liu et al., 2012). The over consumption of the Huanghe water in the upstream leads to the frequent occurrences of zero-water flow days in the downstream. Since 2002, the Huanghe River Conservancy Commission implemented the water-sediment regulation (WSR) trail at the beginning of every flood season. Many studies have examined the impact of WSR on the hydrological processes of the Huanghe River. It was reported that WSR kept the Huanghe water discharges at very high levels within a short period, which is expected to affect the nutrient transports, compositions in the ecosystem of the Huanghe estuary and the adjacent sea (Li et al., 2009; Liu et al., 2012; Han et al., 2013). However, very few studies have focused on the potential impacts of massive water consumption along the river.

In this study, a comprehensive analysis of the riverine nutrient concentrations (including nitrogen and phosphorus) and discharges was conducted in the Huanghe River Basin. The potential impacts of anthropogenic water consumption to the nutrient burden at the estuary of Huanghe River (Bohai Sea) were fully discussed. The contributions from various nutrient sources in different sections of the Huanghe River (upper, middle and lower) were identified using a nutrient mass balance model. This study will help the researchers to gain insight into the positive impacts of human activities to the coastal environment. It will also help regulators develop specific strategies to control riverine nutrient discharges and reduce coastal eutrophication in the Bohai Sea.

2. Methods

2.1. Study area

The mainstream of the Huanghe River and its five largest tributaries (Weihe River, Yiluohe River, Jinghe River, Huangshui River, Qinhe River) were considered in this study (shown in Fig. 1). The Huanghe River was divided into four sections based on geographic features. These include the river source section (mainstream before Lanzhou, Gansu Province, with a length of 2504 km), upper section (from Lanzhou to Huhehaote, Inner Mongolia Autonomous Region, with a length of 968 km), middle section (from Huhehaote to Zhengzhou, Henan Province, with a length of 1206 km) and lower section (from Zhengzhou to Jinan, Shandong Province, with a length of 786 km).

From 2008 to 2012, the annual water discharge of the Huanghe River into the Bohai Sea was approximately 1.8×10^{10} m^3/year (Tong et al., 2015b). During the wet seasons (from May to October), high levels of precipitation generated water flows of 30–46 $\times$ 10^8 m^3/month in the upper Huanghe River, and 16–34 $\times$ 10^8 m^3/month at the estuary (Ministry of Water Sources, 2008–2012). During the dry seasons (from December to April of the next year), flows were 17–20 $\times$ 10^8 m^3/month in the upper stream, and 5–13 $\times$ 10^8 m^3/month at the estuary (Ministry of Water Sources, 2008–2012). The water flows during the WSR trails could account for about 30% of the annual discharges, at the rate of ~40 $\times$ 10^8 m^3/year (Kong et al., 2012; Liu et al., 2012). Compared with the upstream, the reduced water flows in the downstream and estuary was mainly caused by the massive human water consumption. From 1980 to 2012, about 35–94% of the natural water flows in the Huanghe River was consumed by industrial and agricultural usage(Kong et al., 2012), and only a small percent of the water flows was discharged into the Bohai Sea (Fig. 2A). Over 70% of the consumed water was used for agricultural irrigation (Yellow River Conservancy Commission of MWR, 2008–2012) (Fig. 2B).

2.2. Nutrient data

Total nitrogen (TN) and total phosphorus (TP) concentrations were monitored monthly from 2008 to 2012 at the monitoring stations in the Huanghe River Basin (shown in Fig. 1). Field sampling was carried out according to the "Technical Specifications Requirements for Monitoring of Surface Water and Waste Water, in China (HJ/T 91–2002)" by the Chinese Ministry of Environmental Protection. The water sampling sites were all upstream of the sewage outfall to avoid contamination from the point source. Specifically, the vertical water mixture samples (surface: 50 cm under the surface; middle: 1/2 of the river depth; bottom: 50 cm above the riverbed) were collected and mixed for each sampling site. The sampling equipment was cleaned thoroughly with deionized water between each site to avoid cross contamination. Approximately 0.5–1 L water samples were collected each time. As soon as the samples were collected, H_2SO_4 (GR) was added to make the pH < 2. The samples were kept in the refrigerator before analysis at temperature of 4 °C. The measurement of TN was based on the alkaline potassium persulfate digestion ultraviolet spectrophotometric method (GB 11894-89), with a detection limit of 0.05 mg/L. Measurement of TP was based on flow injection analysis and the ammonium molybdate spectrophotometric method (GB 11893-89), with a detection limit of 0.01 mg/L. The TN was measured by ultraviolet spectrophotometer (Mapada Instrument, Shanghai), and the recoveries of standard solutions were $99.0 \pm 6.4\%$. The TP was measured by spectrophotometer (Mapada Instrument, Shanghai), and the recoveries of standard solutions were $100.0 \pm 1.9\%$.

2.3. Nutrient balance

The nutrient sources and discharges in each section (including river source, upper, middle and lower section) of the Huanghe River were divided into four categories: (i) nutrient flowing-out loads with water discharges; (ii) nutrient flowing-out loads with the human water consumption from the selected river section; (iii) nutrient input from the upstream and tributaries; (iv) other nutrient inputs emitted into the river. Based on the input and output nutrient mass balance, the following equation was established for the upper, middle and lower Huanghe River:

$$L_{\text{Upstream In}} + L_{\text{Tributary In}} + L_{\text{Other Emission In}} = L_{\text{Downstream Out}} + L_{\text{Water Consumption Out}} \quad (1)$$

$L_{\text{Upstream In}}$ is the nutrient input from the upstream water (Mg/year). For example, for the lower Huanghe River section, $L_{\text{Upstream In}}$ refers to the nutrient input from the middle Huanghe River section. $L_{\text{Tributary In}}$ is the nutrient input from the tributaries (Mg/year). $L_{\text{Other Emission In}}$ (Mg/year) refers to the other nutrient emissions discharged into the Huanghe River, and it is the sum of the nutrient emissions from point source, non-point sources, etc. $L_{\text{Downstream Out}}$ is the nutrient output with water discharges (Mg/year). $L_{\text{Water Consumption Out}}$ is the nutrient output associated with human water consumption from the river (i.e., agricultural irrigation and