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Impacts of human activities on nutrient transport in the Yellow River: The role of the Water-Sediment Regulation Scheme

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HIGHLIGHTS

- Daily variations of nutrients during WSR period in the Yellow River
- Nutrient changes during water–sediment regulation event.
- The effects of Yellow River sediment–water regulation event on the nutrients' speciation and concentration.
- Sources of nutrients in the downstream of the Yellow River

GRAPHICAL ABSTRACT

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ABSTRACT

Anthropogenic activities alter the natural states of large rivers and their surrounding environment. The Yellow River is a well-studied case of a large river with heavy human control. An artificial managed water and sediment release system, known as the Water-Sediment Regulation Scheme (WSRS), has been carried out annually in the Yellow River since 2002. Nutrient concentrations and composition display significant time and space variations during the WSRS period. To figure out the anthropogenic impact of nutrient changes and transport in the Yellow River, biogeochemical observations were carried out in both middle reaches and lower reaches of the Yellow River during 2014 WSRS period. WSRS has a direct impact on water oxidation-reduction environment in the middle reaches; concentrations of nitrite (NO_2^-) and ammonium (NH_4^+) increased, while nitrate (NO_3^-) concentration decreased by enhanced denitrification. WSRS changed transport of water and sediment; dissolved silicate (DSi) in the middle reaches was directly controlled by sediments release during the WSRS while in the lower reaches, DSi changed with both sediments and water released from middle reaches. During the WSRS, the differences of nutrient fluxes and concentrations between lower reaches and middle reaches were significant; dissolved inorganic phosphorous (DIP) and dissolved inorganic nitrogen (DIN) were higher in low reaches because of anthropogenic inputs. Human intervention, especially WSRS, can apparently change the natural states of both the mainstream and estuarine environments of the Yellow River within a short time.

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1. Introduction

Since the twentieth century, most rivers have been controlled by human beings. (Meybeck, 2003; Milliman et al., 2008). Dams can play a vital role in irrigation, flood control, water regulation and renewable power generation. Besides expected results, dams and reservoirs also lead to some side effects to river systems. These water conservancy

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facilities can influence water flux and sediment flux to the sea (Green et al., 2005; Naik and Jay, 2011; Vörösmarty et al., 1997; Yang et al., 2011). Nutrients flowing to the sea can be modified by changes in water and sediment flux (Carriquiry et al., 2010). Therefore, dams are recognized as affecting natural environments and ecosystems of rivers and coastal ocean. Case studies have reported that many changes of river natural environment were caused by the construction of dams, including Danube River and Guadiana River in Europe, Kurobe River in Japan and many others (Asaeda and Rashid, 2012; Humborg et al., 1997; Morais et al., 2009).

The Yellow River, the second largest river of the world in terms of sediment load, is a well-studied case of a river under anthropogenic control. Excess sediment threaten residents living in the lower reaches. In these areas, the Yellow River deposits much of the sediment in the section where river flows slowly. This accumulation results in the river bed becoming several meters higher than the surrounding plains, increased precarious condition (Chen et al., 2005). Consequently, considerable effort has been made to avoid sediment accumulation and floods. More than 20 large reservoirs have been constructed on the Yellow River and its tributaries since the 1960s (http://www.yellowriver.gov.cn/hhyl/sngc/). With the increasing number of reservoirs on the Yellow River, the water and sediment flux has decreased by 10% - 30% compared to the 1950s (Yu et al., 2013b). However, these reservoirs eventually become filled with sediment, which weakens the water storage function of the reservoirs. In order to mitigate further infilling of sediment in reservoirs and sediment accumulation in the lower reaches of the Yellow River, the Yellow River Conservancy Commission (YRCC) has conducted experiments by releasing a large amount of water and sediment since 2002, called the Water-Sediment Regulation Scheme (WSRS) (Yu et al., 2013a).

Changes in suspended particulate matter (SPM), and the hydraulic characteristics are studied in the Yellow River downstream (Yu et al., 2013a; Yu et al., 2013b). During the WSRS, a huge amount of water and sediment derived from the reservoirs and riverbed are transported to the Yellow River estuary in this pulse delivery (Wang et al., 2006). This great alteration of the hydrological regime must influence the composition and concentration of terrestrial materials reaching the sea (e.g., nitrogen, phosphorous and silicate). Previous studies related to nutrient changes in the Yellow River mainly focused on nutrient flux changes in the lower reaches and estuary (Chen et al., 2005; Chen et al., 2013; Gong, 2012; Liu, 2015; Pu et al., 1999; Tan, 2002; Yao et al., 2009). Some researchers have monitored the monthly variation of nutrients in the lower reaches of the Yellow River, suggesting nutrient transport to coastal sea is intensely high during WSRS (Gong, 2012; Wang, 2007), which to that of whole year was around 50% (Yao et al., 2009). It has been estimated that the WSRS shifted the seasonal patterns of water and nutrients transport which led to a nutrient imbalance, affecting phytoplankton numbers and composition within the adjacent coastal ecosystem (Liu, 2015). However, without observation in the middle reaches, it is still unclear the impact of WSRS on nutrients concentration, composition and transport in the Yellow River as well as the mechanism behind these phenomenon. What are the differences between nutrient compositions and concentration during the WSRS period and non-WSRS? Why is it that nutrients respond to WSRS differently in the lower reaches and middle reaches? How do nutrient flux change when they flow from the middle reaches of the Yellow River to the estuary?

In this study, we will address these questions and assess the influence of the WSRS on nutrients in both the middle reaches and the lower reaches of the Yellow River. We will show a comparison between nutrient behaviors and patterns in the middle and lower reaches during the WSRS. This exploration of the WSRS and anthropogenic activities on nutrient transport in the Yellow River should provide a reference case for other large rivers under heavy human control as a basis for management of the riverine and estuarine environments.

2. Methodology

2.1. Study area

The Yellow River, the second largest river in China, originates from the Qinghai-Tibet Plateau and empties into the Bohai Sea. The total length of the Yellow River is around 5464 km and the estimated total basin area is 795,000 km^2. Pu et al. (1999) estimated that 54% of the water discharge is from the upper reaches while only accounting for 8% of the sediments. The middle reaches passes through the Loess Plateau, which is the major source of the suspended sediments. The lower reach, with a length of around 740 km, flows through the North China plain(Fig.1). This plain covers an area of about 409,500 km^2 and contains more than 300 million people. Therefore, human intervention is a significant factor for the Yellow River (Milliman and Saito 1987). The Xiaolangdi reservoir and Lijin station are key hydrological sites along the mainstream in the middle and lower reaches of the Yellow River, respectively. The Xiaolangdi reservoir is used as the main control for the WSRS. Monitoring hydrological parameters and nutrients at Xiaolangdi station should show how water and sediments released from the reservoir affect the materials in the river. Lijin station is near the river mouth, a good reference point to examine how water, sediments and nutrients changes when they are transported to the estuary and coastal sea.

2.2. General description of the WSRS

Since 2002, the WSRS has been performed annually to regulate and control flow and sediment transportation in the lower reaches of the Yellow River. The WSRS project is very complex and could be divided into several different modes (more details can be found in (Kong et al., 2015b)). Depending on the water level in the Xiaolangdi Reservoir and flood situation in the middle reaches of the river, the multiple reservoirs join operation and artificial stirring is the most commonly used method(Li, 2006, 2012; Li and Sheng, 2011). In order to describe the WSRS systematically, we will use the WSRS in 2014 as an example. By June, 2014, the reservoirs on the mainstreams (including the Xiamenxia Reservoir, Wanjiazha Reservoir and Xiaolangdi Reservoir) stored enough water that would satisfy the required conditions for the implementation of the WSRS before the flood season. The 2014 WSRS can be divided into two stages: first stage is a draining stage, and the second stage is a de-silting stage. In the draining stage, a huge amount of clear water was released from the Xiaolangdi Reservoir. In the de-silting stage, fluid with a high concentration of sediment, was released from the Xiaolangdi Reservoir with assistance of water released from Xiamenxia Reservoir and Wanjiazhan Reservoir (Fig.1). Sand and water pumps were also used to help create the hyper-concentrated flow. When water flows to the estuary from middle reaches, it passes the North China plain, which covers an area of about 409,500 km^2 and contains more than 300 million residents. Therefore, human intervention is a significant factor for the Yellow River (Milliman and Saito 1987). Point source pollution (e.g. industrial wastes and domestic sewerage) and Non-point source pollution, like run off from agricultural area, contribute to the higher nutrients concentration in the lower reaches.

2.3. Sample collection and analysis

Data of water discharge were taken from http://www.yellowriver.gov.cn/nishagonggao. Temperature and pH were analyzed in the field by Orion3 STAR (Thermo Scientific). Water samples were collected at Lijin from 19 June to 16 July, 2014 and from Xiaolangdi from 17 June, 2014 to 10 July, 2014 (Fig. 1). All membranes and bottles that were used in sampling were pre-cleaned with HCl solution (pH = 2) and then rinsed with Milli-Q water. At both stations, 3 parallel samples of river water were collected each day with polyethylene buckets. Afterwards, samples were filtered through 0.45-μm pore-size acetate