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Nutrient variations in the lower reach of Huanghe and their impacts on the Bohai ecosystem

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Major anthropogenic activities in the Huanghe basin and the Bohai

Since the 1950s, more than 3147 dams and reservoirs have been built in the watershed of the Huanghe. Sediment concentration increased dramatically due to cultivation in the loess plateau. Thus the riverbed rose up to 10m above the surrounding area to form a unique "suspended river" and the river course has shifted 11 times in the Huanghe delta since 1855 (Yang et al., 1998). A water-sediment regulation (WSR) scheme has been carried out at flood season since 2002 to improve the proportional relationship between water and sediment loads. During WSR events, freshwater discharge represented 14-55% of annual water discharge; the sediment load accounted for 26-66% of annual sediment load (Figure 1). Although freshwater discharge in the lower reaches of the Huanghe significantly decreased, the water discharge regime remained similar with high values in August to October. The water–sediment regulation events have changed the seasonal patterns of both water discharge and sediment load, causing high monthly water discharge and sediment load advanced to as early as June (Figure 2). In addition, the Bohai has recently experienced rapid coastline changes due to natural developments of the Huanghe delta and large-scale anthropogenic land reclamation. Near-bottom oxygen depleted and coastal acidification have been observed in Northwestern–Northern Bohai (Zhai et al., 2012; Zhao et al., 2016).

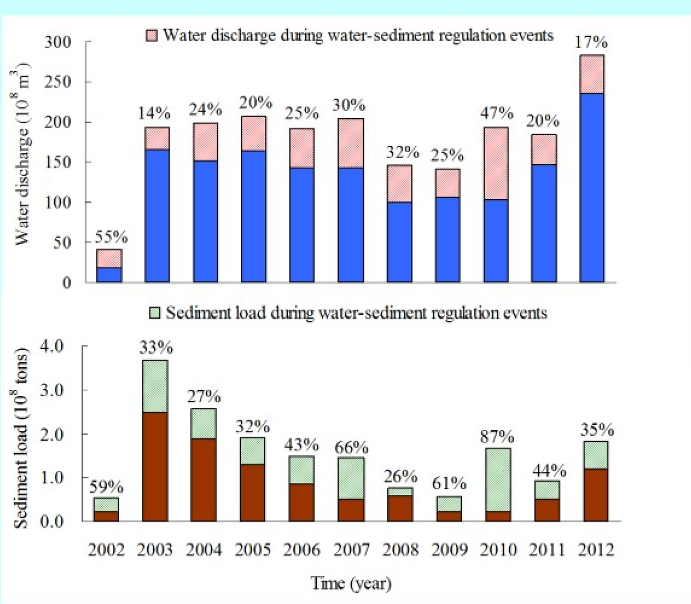

Figure 1 Historical records of freshwater discharge (10^8 m^3) and sediment load (10^8 metric tons) during water–sediment regulation events and their percent (%) of annual freshwater discharge and sediment load, respectively

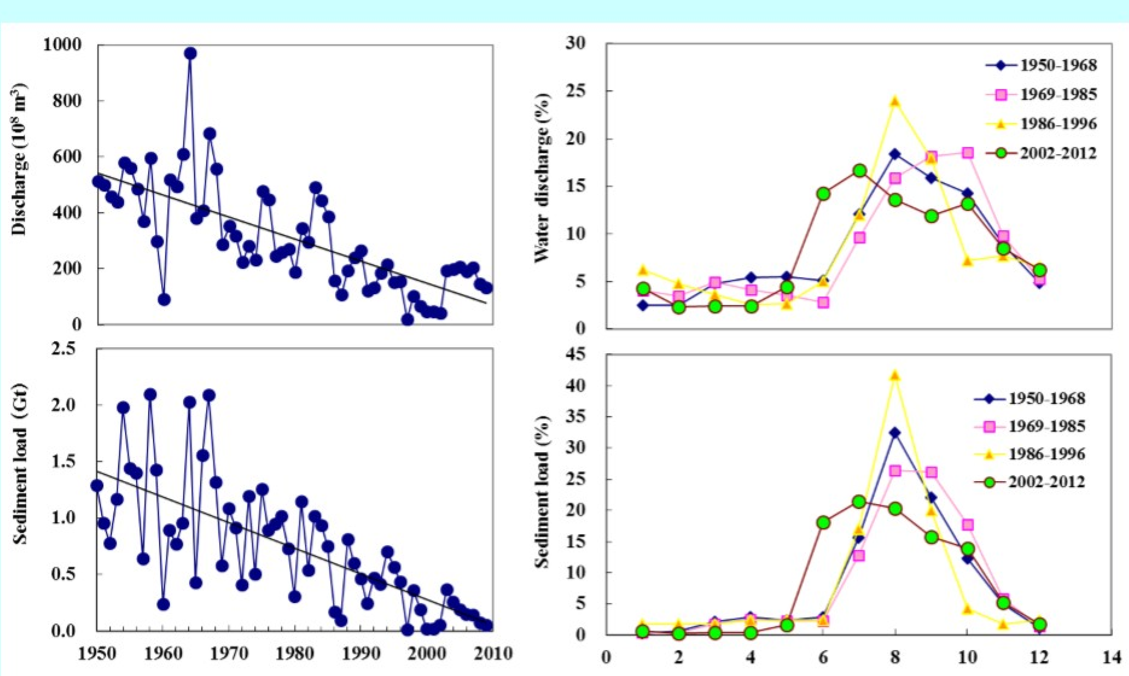

Figure 2 (Left) Annual water discharge and sediment load (Gt = 109 tons) in the lower reaches of the Huanghe since 1950s. (Right) Percent of monthly average freshwater discharge (a) and sediment load (b) in annual water discharge and sediment load at Lijin gauge in different periods (Liu, 2015)

Monthly variations of nutrients in the Huanghe

Nutrient concentrations in the Huanghe are characterized by high concentrations of NO_3^- and H_4SiO_4 but low PO_4^{3-} with very high N/P and Si/P ratios and low Si/N ratio. Compared to other Chinese rivers and the global river data, the Huanghe has relatively high NO_3^- concentrations due to anthropogenic activities, higher concentrations of H_4SiO_4 due to mechanical denudation, chemical weathering, and intense evaporation in the Huanghe basin, and has comparable level of PO_4^{3-} due to abundant suspended particulate matters in the Huanghe. Monthly variations of nutrient transport patterns from the Huanghe to the sea mainly depend on freshwater discharge rate rather than nutrient concentrations.

The effects of Huanghe water-sediment regulation and rainstorm events on nutrient transports

WSR event substantially changed water and nutrient transport fluxes (Figure 3), with similar variations for water and dissolved nutrient elements, and dramatically increased particulate nutrient fluxes than freshwater discharge. Before the implementation of the manipulation, observations in 2001 were the only case available as a reference. For 2001 water discharge in 30 days in flood season represented 6% of annual water discharge and dissolved nutrient fluxes accounted for the similar amount (Figure 4). Moreover, from 2002 to 2012, nutrient fluxes during WSR and rainstorm periods accounted for 5-59% and 23-68% with averages of 38% and 24% of annual nutrient fluxes, respectively (Wu et al., 2017).

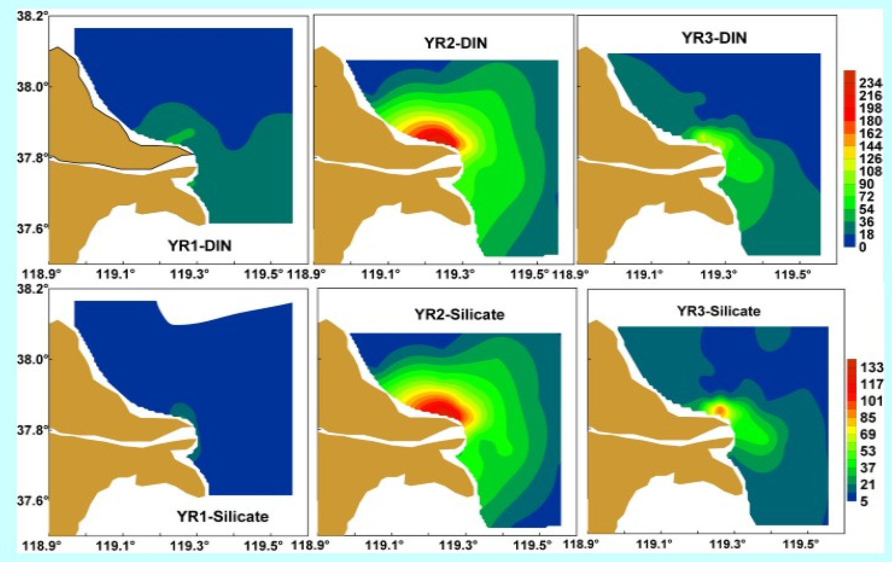

Figure 3 Horizontal distributions of nutrient concentrations (μmol L^{-1}) in the Huanghe Estuary before, during and after the water-sediment regulation event.

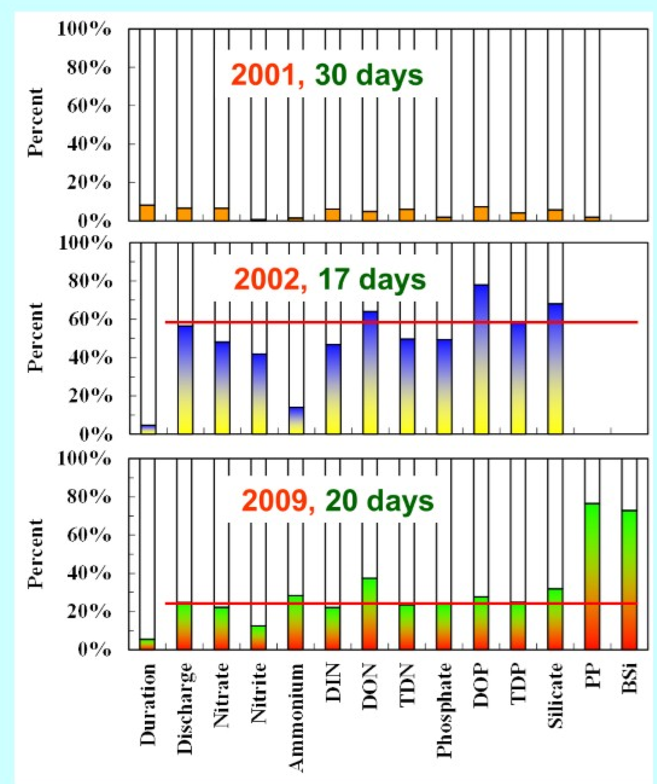

Figure 4 The impact of WSR events, which show percents of annual total, including duration of the regulation events, water discharge, and nutrient transports in 2002 and 2009. The case in 2001 was given with monthly averages in June and July as a comparison before the implementation of the regulation. Data in 2001 and 2002 are sourced from Yao et al. (2009) and Zhang et al. (2010).

To understand the nutrient imbalance resulted from the WSR event, the indicator of coastal eutrophication potential (ICEP) of terrigenous nutrient inputs is addressed based on the flux of nitrogen (N-ICEP) or phosphorus (P-ICEP) delivered in excess over silica and is expressed in terms of carbon equivalence (Garnier et al., 2010). The monthly Huanghe transports show negative P-ICEP values but positive N-ICEP values (Figure 5). This indicates that the WSR event may not only increase nutrient inputs and change the nutrient transport patterns to the coastal ecosystem but also aggravate nutrient imbalance.

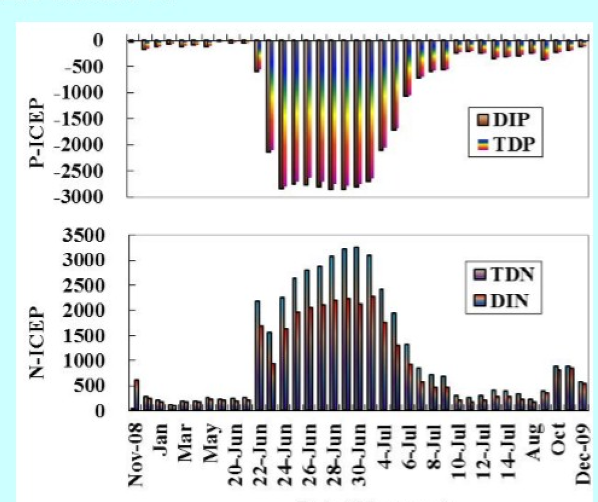

Figure 5 Daily (left, 2008–2009) and monthly (right, 2001–2011) variations of freshwater discharge (m^3 s^{-1}) and P- and N-ICEP (×10^5 mol C day^{-1}) in the Huanghe

Potential impacts on the Bohai ecosystem due to artificial floods in the Huanghe basin

During the last three decades (1982–2009) in the Bohai, concentrations of dissolved inorganic nitrogen increased 3–9 times likely due to agricultural activities. Concentrations of phosphate and dissolved silicate decreased 2–6 times probably resulting from a decrease in phosphorus-containing detergent use and a decrease in the river water discharge. Accordingly, DIN/P ratios, while Si/DIN ratios decreased (Zhang et al., 2004; Liu et al., 2008, 2011; Ning et al., 2010). Phosphorus limitation for phytoplankton growth should become more serious, especially during the WSR event. The ratio of diatoms to dinoflagellates has been reduced (Kang, 1991; Wang and Kang, 1998; Sun et al., 2002). The annual cycle of phytoplankton biomass in the Bohai Sea has been characterized by double-peak configuration in March or April and in July to October (Fei et al., 1991; Lü et al., 1999; Sun et al., 2003). As changes in nutrient transport patterns from the Huanghe could compensate for the nutrients consumed during the spring bloom and may more likely lead to the second algae bloom being initiated earlier than before and with a different phytoplankton composition.

Conclusions

The concentrations and composition of nutrients in the Huanghe had an obvious change during the WSR events, which increased dissolved nutrient transports with similar amplitude like freshwater discharge, while amplified particulate nutrient transports. Nutrient transport patterns highly depend on freshwater discharge. The regulation events have shifted the seasonal patterns of water and nutrient transports with high flow condition occurring at least two months prior to the normal peak flow. Abundant nutrients were transported to the coastal water and nutrient imbalance was aggravated, most likely resulting in strong impacts on the adjacent Bohai ecosystem.

Major references (omitted)

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