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Flux characteristics of total dissolved iron and its species during extreme rainfall event in the midstream of the Heilongjiang River

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ABSTRACT

The occurrence of extreme rainfall events and associated flooding has been enhanced due to climate changes, and is thought to influence the flux of total dissolved iron (TDI) in rivers considerably. Since TDI is a controlling factor in primary productivity in marine ecosystems, alteration of riverine TDI input to the ocean may lead to climate change *via* its effect on biological productivity. During an extreme rainfall event that arose in northeastern China in 2013, water samples were collected in the midstream of the Heilongjiang River to analyze the concentration and species of TDI as well as other basic parameters. The speciation of TDI was surveyed by filtration and ultrafiltration methods. Compared with data monitored from 2007 to 2012, the concentration of TDI increased significantly during this event, with an average concentration of 1.11 mg/L, and the estimated TDI flux reached 1.2×10^5 tons, equaling the average annual TDI flux level. Species analysis revealed that low-molecular-weight complexed iron was the dominant species, and the impulse of TDI flux could probably be attributed to the hydrological connection to riparian wetlands and iron-rich terrestrial runoff. Moreover, dissolved organic matter played a key role in the flux, species and bioavailability of TDI. In addition, there is a possibility that the rising TDI flux could further influence the transport and cycling of nutrients and related ecological processes in the river, estuary coupled with the coastal ecosystems, which merits closer attention in the future.

Introduction

Iron, a critical nutrient element in aquatic ecosystems, participates in most physiological processes of organisms (Zou et al., 2011). Reportedly, in comparison with balanced cell growth on the basis of fixed nitrogen, a 60- to 100-fold higher iron concentration was required in diazotrophy development in cells of planktonic diazotrophic cyanobacteria, such as *Trichodesmium*, the predominant autotrophic diazotroph in the pelagic marine environment (Berman-Frank et al., 2001; Brand, 1991). The biogeochemical effects of total dissolved iron (TDI) rely on both its concentration and speciation, including ferrous (Fe(II)) and ferric (Fe(III)) iron, organically and inorganically complexed iron and colloidal iron (Stumm and Sulzberger, 1992). In rivers, the ionic iron largely involves Fe(II) since Fe(III) is extremely insoluble, but it can be dissolved by means of binding to dissolved organic matter (DOM) to enhance the overall solubility, and most (>99%) of the dissolved Fe(III) emerges in organic complexed form (Perdue et al., 1976;

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Meunier et al., 2005). Recently, the riverine input to the ocean, which is one of the primary sources of TDI in the ocean, has attracted increasing attention because of the likelihood that riverine input will generate climate changes, by virtue of its effect on primary biological production and the carbon sequestration rate in ocean regions (Blain et al., 2007; Chen et al., 2014).

Rainfall and subsequent territorial runoff are the chief driving forces of TDI transport (Vuori, 1995). On account of climate change, the occurrence of extreme rainfall events and associated flooding has been heightened worldwide in recent decades, especially in temperate areas at high latitudes (IPCC, 2012). This results in momentous changes of regional hydrology together with ecosystem processes and services, such as the biogeochemical cycles of nutrient elements (Knapp et al., 2008). Variations of DOM and nutrients have been studied intensively during an extreme rainfall event (Siemann et al., 2007); nevertheless, the transport and flux of TDI, the mobility of which can be impacted strongly by rainfall events, has rarely been documented.

The Heilongjiang River (also called the Amur River), located in northeastern China, flows into the Okhotsk Sea, which has a relatively high abundance of phytoplankton biomass because of the sufficient TDI transported from the Heilongjiang River (Yoshimura et al., 2010). A surge of TDI flux related to the flood in 1998 was documented during the late 1990s in the midstream of the Heilongjiang River (MHR) (Kulakov et al., 2010). A similar trend was also observed during intensive rainfall events in different studies, which might owe to the iron-rich runoff and large amounts of DOM inputs (Abesser et al., 2006; Jiann et al., 2013). An extreme rainfall event occurred in August, 2013 in northeastern China, causing severe flooding in the Heilongjiang River. Driven by the desire to understand the alteration of TDI flux resulting from this extreme event, this article presents the water quality data of MHR within the period of the extreme rainfall event as well as historical data from 2007 to 2012, (1) to study the characteristics of TDI flux and species during the extreme rainfall event, (2) to investigate the sources and critical decisive factors of this process, and (3) further to discuss the potential effects of an impulse flux of TDI to the aquatic ecosystem.

1. Materials and methods

1.1. Study area

The Heilongjiang River, stretching from western Manchuria to the Strait of Tartary, whose length is 2825 km (mainstream) with a catchment area about 1.85 million km^2, of which 48% is located in northeastern China, is the tenth largest watercourse in the world (Yan et al., 2013).

MHR is defined as the river section between the embouchures of the Zeya River (Blagoveshchensk City) and Ussuri River (Khabarovsk City), with a length of approximately 950 km. Not only snowmelt in spring but also monsoonal rain in the course of summer to autumn, which accounts for 15%–20% and 65%–80% of total runoff supply, respectively, comprises the main sources of the flow (Yan et al., 2013). Extensive lowland wetlands exist widely in the basin of MHR, which serves as vital parts in buffering floods and biogeochemical processes in the river ecosystem. In the junction of the Heilongjiang River, the Songhua River and the Ussuri River lie along Tongjiang City and Fuyuan City (Fig. 1), where the annual average temperature is 2–3°C, precipitation around 600 mm per year, of which nearly 80% occurs from June to September, and frost period about 180 days per year, lasting from late October to April of the next year.

The average annual discharge of MHR is 8260 m^3/sec, which has fluctuated from 4290 (in 1979) to 14,000 (in 1897) m^3/sec, with maximum flow of 39,200 m^3/sec recorded in 1897 at Khabarovsk. The MHR has a water catchment area of 1.63 million km^2, accounting for 87.9% of the total basin area of the Heilongjiang River, with the main control station situated in Khabarovsk City after the convergence of the Rivers of Zeya, Bureya, Songhua and Ussuri (Yan et al., 2013).

1.2. The extreme rainfall event

An extreme rainfall event in this study is defined as rainfall with precipitation over 20 mm with a high frequency (average frequency 3.78 times per year) within a gap of 1–5 days (Yang et al., 2008). In 2013, four intensive rainfall events with precipitation over 20 mm were monitored from August 14th to 22nd in the research area (Fig. 2), which could be defined as “extreme rainfall event”. The water level in MHR peaked around September 1st during the event and ebbed away to the normal level on September 22nd. No extreme rainfall event was observed during 2007–2012 in this area. The runoff depth during the extreme rainfall event was calculated according to the Soil Conservation Service Curve Number (SCS-CN) method (Mishra and Singh, 2003).

1.3. Sample collection and analysis

Water samples were taken from the depth of 50 cm below the water surface at Tongjiang City and Fuyuan City (Fig. 1) in the flood period (July and August) after the rainfall and normal flow period (May, June, September and October) from 2007 to 2012, as well as in the period of the extreme rainfall event from August to September in 2013. After collection, all samples were then stored in a portable refrigerator (4°C)

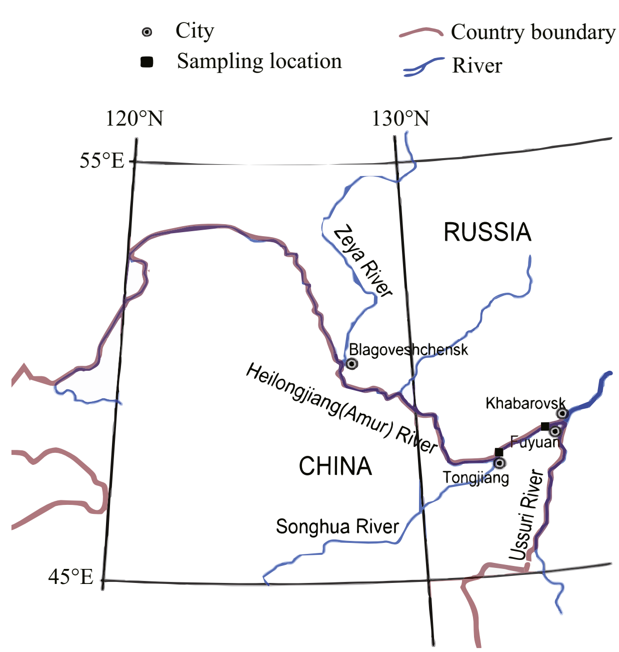

Fig. 1 – Location of sampling sites in the midstream of the Heilongjiang River (MHR).