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Seasonal variation in river water chemistry of the middle reaches of the Yellow River and its controlling factors

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ABSTRACT

In order to reveal the seasonal variations of river water chemistry and its controlling factors in the middle reaches of the Yellow River, river water samples were collected weekly from the Longmen hydrological station over the whole year of 2013. Major cation and anion compositions were measured. The major ionic compositions of the dissolved load exhibited distinct seasonal variability over the one year period, reflecting seasonal differences in relative inputs from various sources and weathering reactions within the catchment. A forward model was used to calculate the apportionments of rain, anthropogenic, silicate, evaporite, and carbonate origins on a seasonal basis. The contributions of both rain and anthropogenic sources to the middle Yellow River were less than ~12% in average, with little seasonal variations in 2013. The calculations showed that silicate sources had a relatively large impact on water chemistry during the pre- and early-monsoon seasons, though both silicate and carbonate weathering increased greatly during the monsoon season. The high silicate input during the pre- and early-monsoon seasons was attributed to the waters potentially derived from plateau headstream, glacial melting, and soil pore. Meanwhile, the dominated contributions of evaporites and carbonates in the late- and post-monsoon seasons were resulted from their rapid dissolution from the loess plateau through physical erosion acceleration along with high water discharge, because widespread loess is characterized by easy denudation and high carbonates and evaporites. Our densely time-series data also highlighted a significant impact of extreme hydrological events on water chemistry in semi-arid area. During the ice melting interval in the springtime, more silicate-origin ions entered the river from melting water, whereas during the stormy event interval in the peak monsoon, more carbonates and evaporites reached the Yellow River from the loess plateau via accelerated physical erosion. Our data shed further light on processes responsible for seasonal variation of river chemistry of the Yellow River and modern loess weathering.

1. Introduction

As the fifth longest river in the world and the second largest by length (5464 km) and basin area (752,400 km^2) in China, the Yellow River originates from the eastern Tibetan Plateau and is characterized by extremely large sediment load, contributing significantly to global riverine sediment supply (Milliman and Syvitski, 1992; Zhang et al., 1995) and potentially to global marine solution chemistry (Jacobson, 2004). The high sediment load of the Yellow River is eroded mostly from its middle reaches when it flows across the Chinese Loess Plateau (CLP) which comprises 440,000 km^2 with thickness of loess >100 m (Liu, 1985). Thus, much attention has been paid to the flux and change of sediment loads in the Yellow River at various periods (e.g., Martin et al., 1993; Milliman et al., 1987; Ren and Zhu, 1994; Wang et al., 2007), and to water chemistry associated with loess weathering (Hu et al., 1982; Li and Zhang, 2003; Wu et al., 2005; Zhang and Wen, 2009; Zhang et al., 1995).

Hu et al. (1982) reported the first data on water chemistry of the Yellow River. The river water sample was collected in October 1978 from one site near Sanmenxia. Zhang et al. (1995) collected 10 water samples in August 1986 from 10 sites to discuss the weathering processes and chemical fluxes of the Yellow River. Similarly, Li (2003)analyzed 14 river water samples collected in the August 2000 and dry season of 2001 along the Yellow River and roughly estimated the contribution of silicate, carbonate, evaporite, and atmosphere to river water chemistry. Furthermore, Zhang and Wen (2009) calculated the silicate weathering and its CO_2 consumption rate of the Yellow River by using a forward model; the river water samples were collected during the monsoon 2007 from 13 sampling sites. The sampling sites were scattered from upper to lower reaches of the river and sampling was limited to one specific date. Wu et al. (2005) concentrated on the upper reaches of the Yellow River and used an inverse model to calculate the silicate weathering rate and CO_2 consumption rate by sampling in May to June 1999 and June 2000. These previous studies indicate that

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the waters in the Yellow River are dominated by carbonate and evaporite weathering with limited silicate contribution. The dominance of carbonate weathering can be attributed to rapid denudation and weathering of loess, since loess is characterized by easy denudation and high carbonates.

Considering that carbonate weathering is sensitive to monsoon climate (Jin et al., 2011; Tipper et al., 2006; Zhang et al., 1990a) and that loess covers 40% area of the Yellow River drainage basin, estimates of weathering and CO_2 consumption rates may be biased by sampling at rain and/or dry seasons only, or by missing some extreme events. Moon et al. (2014) suggested that at least 10, preferably ~40, temporal chemical data points with synchronous discharge are necessary to reduce the uncertainties of silicate weathering estimates. Therefore, time-series sampling studies on the Yellow River are required to further understand its weathering processes and its sensitivity to the East Asian and Indian summer monsoons.

In order to better trace the seasonal river water chemistry and its controlling factors in the middle reaches of the Yellow River, river water samples were collected weekly at the Longmen hydrological station. This station is located in the middle Yellow River where waters from most tributaries draining the CLP converge (Fig. 1). The goals of this study are (1) to examine the major cation compositions of the dissolved loads and their seasonal variations, (2) to catch signatures of erosion and weathering following some extreme hydrological events (storm, ice melting), (3) to estimate respective contributions of carbonate and silicate weathering and their CO_2 consumption rates, and (4) to address controlling factors of seasonal variations in river water chemistry at the middle reaches of the Yellow River.

2. Study area

2.1. Geography

The entire Yellow River drainage basin is situated at 32°–42° N and 95°–120° E. The river originates from northeast of the Tibetan Plateau (35°01′18″ N, 95°59′24″ E) at an altitude of 4500–5000 m, turns to towards the east and flows down the plateau near Lanzhou City, then crosses over the CLP and great Huang Huai plain, and finally goes into the Bohai Sea (Wu et al., 2008). The middle reaches of the river are delineated between Hekou Town (Toudaoguai) and Taohuayu near Zhengzhou City (Fig. 1).

The upper watershed of the Yellow River provides about 60% of annual water discharge but only 10% of annual sediment load, whereas the tributaries draining the CLP in the middle reaches contribute about 40% of the annual water discharge and 90% of annual river sediment load (Zhang et al., 1990b). There are a large number of large tributaries upstream of the Longmen hydrological station, including the Tao, Huangshui, Zuli, Qingshui, Dahei, Kuye, and Wuding Rivers joining into the Yellow River (Fig. 1). Among them, the Zuli, Qingshui, Dahei, Kuye, and Wuding Rivers originate and flow through the CLP, contributing most of sediment loads of the Yellow River annually. These rivers mainly originate from the basins between the Toudaoguai and Longmen hydrological stations (Fig. 1). The mainstem of the Yellow River between Toudaoguai and Longmen, flowing through the narrow gullies with steep slopes, is 725 km long and 400–600 m wide. Moreover, there are 21 secondary tributaries, which mainly develop in the loess hills and gully areas, with a catchment area lager than 1000 km^2 (Jiao et al., 2014).

2.2. Geology

The bedrocks of the drainage basin of the Yellow River was formed during the Archaeozoic and Proterozoic Eras, and the main bedrocks scattered in the upper basin are detrital rocks, dominated by shale (Chen et al., 2005). The middle reaches of the Yellow River are dominated by Quaternary loess and loess-like deposits where it is the largest loess covered area in the world. Loess mainly formed by the accumulation of wind-blown dust in Quaternary is homogeneous, porous, friable, pale yellow, slightly coherent, typically non-stratified and often calcareous (Liu, 1985). Owing to huge and steep landscape, low vegetation

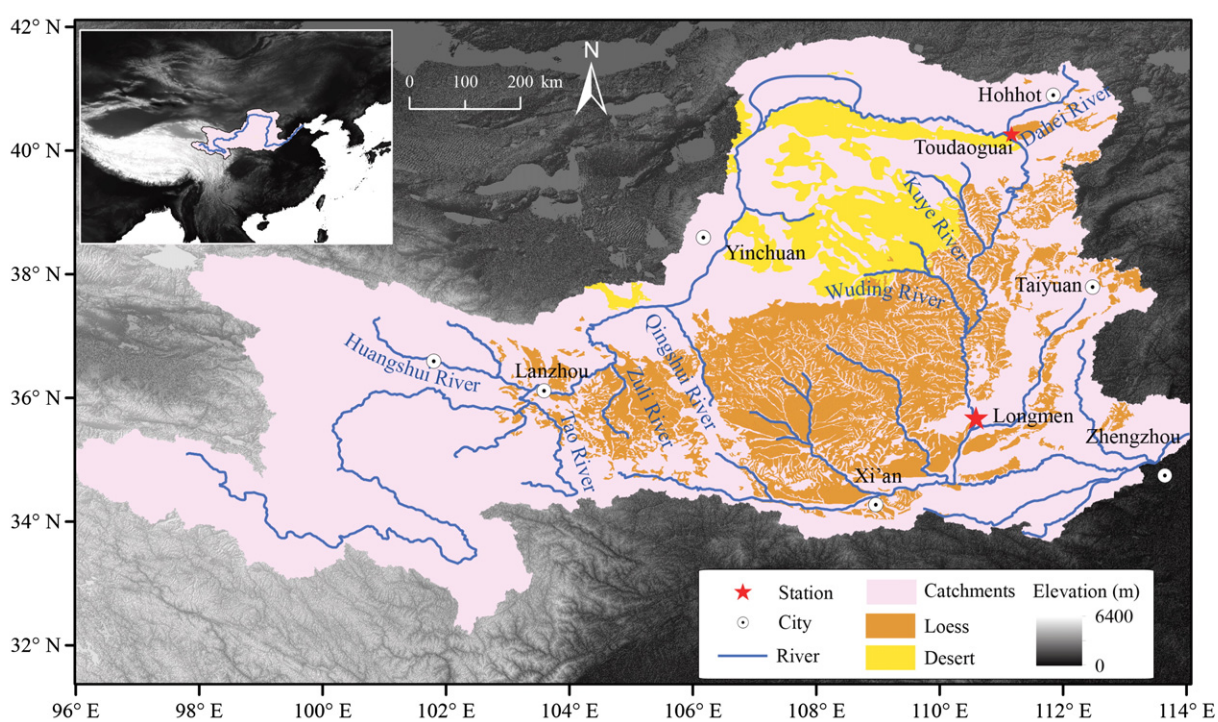

Fig. 1. Map showing the sampling locations, and the distribution of two kinds of lithology (loess, desert) within the upper and middle reaches of the Yellow River. Inset shows the entire Yellow River drainage basin.