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Analysis of channel evolution characteristics in the Hobq Desert reach of the Yellow River (1962–2000)

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ABSTRACT

A series of problems, resulting from sediment deposition and channel silting, have occurred on the Hetao Plain as a result of changes to the Hobq Desert reach of the Yellow River. Therefore, improved research on channel evolution in this reach is vitally important. Using profile data from 80 channel cross-sections obtained in 1962, 1982, 1991 and 2000 from the Yellow River in the Hobq Desert, we showed that there was serious sediment deposition here (especially for the tributary section in the eastern desert) and that maximum sediment deposition occurred during 1982–1991. As sediment was deposited along the mobile channel, the channel trunk shrank and moved to the north. The characteristics of river channel evolution are dramatically different between the western and the eastern Hobq Desert reaches of the Yellow River, which include desert and the tributary sections, respectively. Erosion mainly occurred in the desert section, whereas sediment deposition occurred in the tributary section, with peak values at the mouths of on Yellow River tributaries. The desert section had a larger average erosion rate and smaller accumulation rate than the tributary section. The influences of tectonic movement and stream gradient on channel evolution in this fluvial reach were minimal. The sediment inputs from ten Yellow River tributaries (especially during flood seasons) have dominated channel evolution in these tributaries. The building of artificial levées has intensified sediment deposition in the channel, whereas the reduction of mainstream discharge (especially in the flood seasons), caused by the operation of reservoirs and water diversion activities (such as for agricultural irrigation), has further intensified the sediment deposition in the river channel.

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1. Introduction

The Yellow River is the second largest river in China and is famous for its high sediment concentrations, frequent floods, rapid sedimentation rate and unique channel characteristics in the lower reaches (sedimentation causes the riverbed to rise higher than the adjacent land in what is known as a "hanging river"), and it is currently an overtaxed water resource (Xu, 2002; Yu, 2002; Fu et al., 2004; Sato et al., 2008; Wang et al., 2012). The Hobq Desert reach is in the lower section of the upper Yellow River, starting at the city of Linhe and ending at the city of Tuoketuo (Fig. 1), with a total channel length of approximately 435 km. The climate of this region is arid. The mean annual rainfall ranges from 200 to 250 mm, with a potential evaporation of 1000 to 2000 mm (Yao et al., 2011). The Hetao Plain, through which the Hobq Desert reach of the Yellow River extends, is an important energy base and a primary grain producing area in northwestern China; it also plays a decisive role in both the industrial and agricultural economy. Because of a low gradient and unconsolidated fluvial sediment, this reach is characterized by high sediment loads, substantial sediment deposition (the channel has clearly elevated and an almost 150 km long "hanging river" has appeared in recent decades), extensive channel migration and frequent breaching of levées, all of which have brought about substantial social, economic and environmental problems on the Hetao Plain (Li et al., 2003; Ta et al., 2008; Shi, 2010; Yao et al., 2011; Wang et al., 2012).

Researchers have undertaken numerous studies of the Hobq Desert reach of the Yellow River. In general, previous studies have mainly been concerned with variations in fluvial discharge and sediment concentration, calculating erosion and sedimentation changes, channel responses to reservoir construction upstream, changes in the sediment grain size in the river bed, the origins of coarse sediment in the river and suspended sediment dynamics (Wang et al., 1996, 2007, 2012; Zhao et al., 1999; Yang, 2002; Ta et al., 2003, 2008, 2011, 2013; Ran et al., 2010; Yao et al., 2011; Fan et al., 2012, 2013). There are multiple negative impacts that have resulted from river channel evolution in the study reach, caused by the deposition and erosion of sediment. To reduce or avoid these negative impacts, we must first understand the characteristics of river channel deposition and the evolution of erosion and their controlling factors. In terms of quantifying channel deposition, most calculations have been based on observational data (suspended sediment concentration) from hydrological stations; this method

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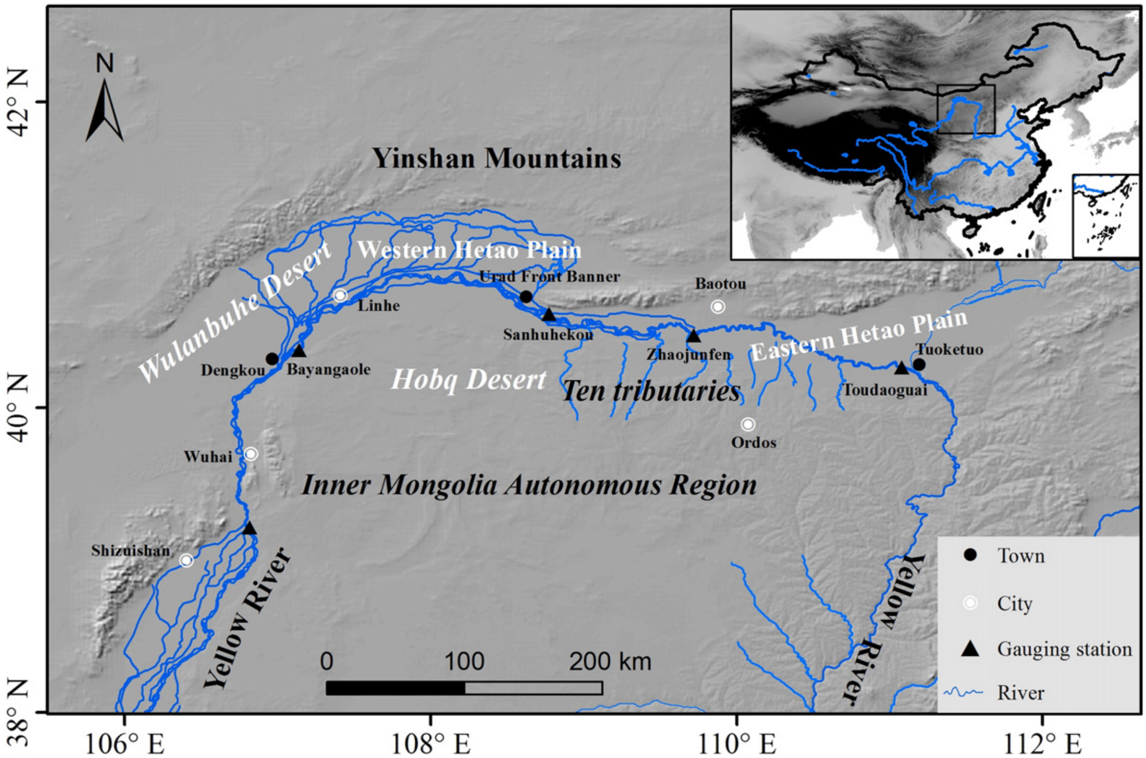

Fig. 1. The Hobq Desert reach in the upper reaches of China's Yellow River.

could roughly reflect the sediment deposition and erosion evolution of the riverbed, but some of the details are not easily deduced, such as the deposition characteristics in the river channel and floodplain (Ta et al., 2003; Wang et al., 2007, 2012; Ran et al., 2010; Fan et al., 2012). Measured data from river cross-sections can be used not only to correct imperfections in the hydrological observation data, but also to determine the specific changes to the river channel and floodplain. These studies have been conducted recently and some significant progress has already been achieved. For instance, Ta et al. (2013) discussed channel deposition on the sand-banked part of the Hobq Desert reach of the Yellow River using measured data from river cross-sections. Nevertheless, studies about the channel evolution characteristics of the whole study reach, using measured river cross-section data, remain scarce. There have been earlier interpretations of channel sediment erosion and deposition in this reach. For example, Wang et al. (1996) and Zhao et al. (1999) ascribed channel aggradations in the Inner Mongolia reach to the deposition of sediment eroded from the tributaries on the Loess Plateau under low discharge regulation conditions in the upstream reservoirs. Ta et al. (2008) and Yang (2002) suggested that channel aggradation was induced by perennial sediment input from the surrounding deserts.

In this paper, the temporal and spatial characteristics of active channel evolution in the Hobq Desert reach of the Yellow River have been analyzed using measured river cross-section data and remote sensing data. On this basis, we can discuss the reasons for channel sediment erosion and deposition, as well as channel migration, and provided theoretical support for the operation and management of this reach.

2. Study area

The Inner Mongolia reaches of the Yellow River are characteristic desert gully reaches (Fig. 1). Due to a low gradient and loose riverbed materials, the reaches are characterized by severe channel-bed siltation (the riverbed has risen markedly and a nearly 150 km channel length has become a “hanging river” in recent decades), major channel migration, and frequent breaching of levées, all of which have introduced significant social, economic and environmental problems to residents along the river (Ta et al., 2008; Yao et al., 2011; Wang et al., 2012).

The Inner Mongolia reaches of the Yellow River are located along the fringe of the East Asian monsoon belt, with a continental climate, and have a low and unevenly distributed annual precipitation (150–363 mm). Westerly and northwesterly winds (Mean Annual Wind Speed: 2.7–4.5 m s^{-1}) predominate. The duration of sunlight is long (≥10 °C accumulated temperature 3004–3515 °C), and the evaporation is intense (annual mean evaporation 1939–3482 mm is as much as 10–12 times precipitation) (Yang, 2002). Ten tributaries (cross-desert ephemeral tributaries) flow through the Kubq Desert and join the Yellow River on its right bank; they frequently deliver mudflows into the trunk channel (Fig. 1) and are thus the main sources of coarse sediment in the study reach (Ta et al., 2008, 2011).

3. Materials and methods

To understand channel changes in the Hobq Desert reach in relation to flood control measures, the Yellow River Conservancy Commission of China (YRCC) began, in 1962, to establish 113 channel cross-sections at approximately 5-km intervals along the active channel from Linhe to Toudaoguai (Fig. 2). These profiles were surveyed in 1962, 1982 and 1991 by the YRCC and were resurveyed by the Inner Mongolia Water Conservancy and Hydropower Survey and Design Institute of China in 2000. Based on manual drawings of each measured section, we digitally processed them using ArcGIS (Version 9.3). Eighty cross-sections of good quality, covering four fully complete periods, were selected from the 113 cross-sections and analyzed (Fig. 2). By using these profile data, we calculated the volume and velocity of erosion and deposition of river channel sediment, river bank displacement and the width of the river channel during the following four periods: 1962–1982, 1982–1991, 1991–2000 and 1962–2000. The following calculation method was used:

We considered the location of levées in cross-sections as marking the river boundary and the area between the river channel inside the levées and the abscissas as the cross-section area (Fig. 3). Then, the

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