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Spatial and temporal variations of aeolian sediment input to the tributaries (the Ten Kongduis) of the upper Yellow River

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ABSTRACT

The Ten Kongduis of the upper Yellow River, located in Inner Mongolia, northern China, is an area with active wind-water coupled erosion and hence one of the main sediment sources of the Yellow River. In this study, we analyzed the characteristics of spatial and temporal variations of aeolian sediment input to the river channel. For this purpose, three segments of sand dune-covered banks of the Maobula and the Xiliugou kongduis were investigated three times from November 2014 to November 2015 using a 3-D laser scanner, and the displacement of banks of desert reaches of three kongduis was derived from interpreting remote sensing images taking in the years from 2005 to 2015. The data of the surveyed sand dunes reveal that the middle kongduis were fed by aeolian sand through the sand dunes moving towards the river channels. The amount of aeolian sediment input was estimated to be about 14.94×10^4 t/yr in the Maobula Kongdui and about 5.76×10^4 t/yr in the Xiliugou Kongdui during the period from November 2014 to November 2015. According to the interpretation results of remote sensing images, the amount of aeolian sediment input to the Maobula Kongdui was about 15.74×10^4 t in 2011 and 18.2×10^4 t in 2012. In the Xiliugou Kongdui, it was in the range of $9.52 \times 10^4 - 9.99 \times 10^4$ t in 2012 and in the springs of 2013 and 2015. In the Hantaichuan Kongdui, it was 7.04×10^4 t in 2012, 7.53×10^4 t in the spring of 2013, and 8.52×10^4 t in the spring of 2015. Owing to the changes in wind and rainfall, both interseasonal and interannual sediment storage and release mechanisms exist in the processes of aeolian sand being delivered into the kongduis. However, all of the aeolian sediment input to the Ten Kongduis should be delivered downstream by the river flows during a long term.

1. Introduction

In arid and semi-arid zones, wind erosion is an important environmental issue that affects 28% of the global land area experiencing the land degradation (Buschiazzo and Zobeck, 2008; Webb et al., 2006). Aeolian-fluvial interactions mainly control the extent, shape and boundaries of an individual dunefield (Bullard and McTainsh, 2003). In aeolian and fluvial coupled system, rivers usually act as the boundaries of aeolian transport, and aeolian sand is a main source of sediment (Bullard and Livingstone, 2002). Effects of aeolian activity on fluvial systems include diversion and damming of rivers (Mason et al., 1997), narrowing or constriction of valleys (Marker, 1977), channel avulsion (McIntosh, 1983; Jacobberger, 1988; Jones and Blakey, 1997; Bourke and Pickup, 1999) and bifurcation (Tooth, 1999) and waterhole development (Knighton and Nanson, 1994). Ephemeral rivers can be blocked or diverted by sand dunes (Teller and Lancaster, 1986; Jia and Wang, 2014).

In general, the aeolian sand input to the river channel includes the sediment blown into the river channel by winds directly, and the collapse of sand dunes on the banks due to river lateral erosion (Yang et al., 1988). The factors influencing the amount of aeolian sand input and its contribution to the sediment yield of a basin are diverse, including topography, wind, water and the angle of the river with the wind directions and so on. The complicated factors make it difficult to calculate the amount of aeolian sand input accurately with the traditional research methods and measurements (Bullard and Livingstone, 2002). Recently, the development of remote sensing technology provides many new methods for monitoring surface morphology (Tarolli et al., 2009), in which the terrestrial laser scanning (TLS) technology and the remote sensing images have been widely used in the study of surface process by lots of scholars (Werner and Andreas, 2005; Milan et al., 2007; Williams et al., 2014; Yao et al., 2011; Ta et al., 2013; Liu and Coulthard, 2015).

The Kubuqi Desert is located in the northern part of the Ordos

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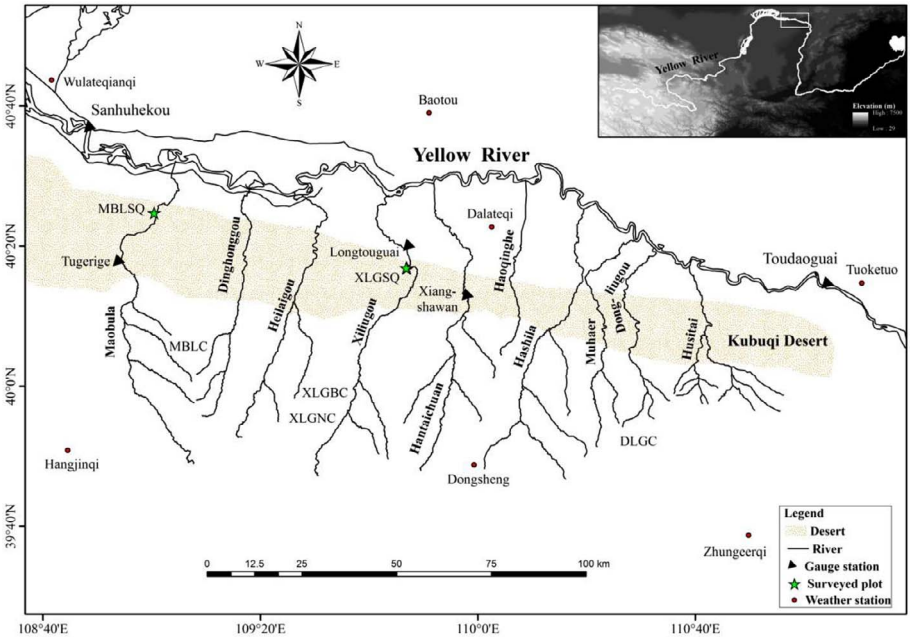

Fig. 1. Locations of the Ten Kongduis and the plots surveyed.

Plateau in Inner Mongolia, China. It is bordered by the Yellow River to the west, north and east, and its terrain slopes gently from south to north (Du et al., 2014). The eastern part of the Kubuqi Desert crosses the middle reaches of ten tributaries of the Yellow River and these tributaries are called the Ten Kongduis (kongdui is the transliteration of ephemeral flood gullies in Mongolian). Given the special location of the Kubuqi Desert, the wind and water erosion are strongly coupled in the Ten Kongduis basins. Aeolian sediments could be deposited and stored in the channels of the Ten Kongduis during the windy seasons, and they might be washed away by floods during the following wet seasons. According to the previous studies on the sediment yield and sediment delivery of the Ten Kongduis, the aeolian sand in the middle reaches is one of the main sediment sources and highly promotes the sediment content of floods from the upper reaches (Xu, 2014). The sediment-laden floods have frequently destroyed railways, highways, and factories located in the lower regions of the Ten Kongduis and the sediment yielded from the kongduis has caused serious silting in the Yellow River.

The research about the amount of aeolian sediment input to the kongduis so far is still few. Through simulating the daily saltation emission in the Kubuqi Desert by a saltation submodel of the Integrated Wind-Erosion Modeling System, Du et al. (2014) estimated that the annual quantity of aeolian saltation sand that was deposited in the Ten Kongduis ranged from 0.0204×10^8 t to 0.139×10^8 t during the period from 2001 to 2010. However, this simulated result has not been validated via field observation and measurement. The process of fluvial-aeolian interaction was investigated by Ma et al. (2013) in a tributary of the Dinghonggou Kongdui and by Wang and Ta (2016) in a tributary of the Maobula Kongdui. Ma et al. (2013) find the ratio of wind erosion and water erosion to be 1.8:1 for the year 2010. Wang and Ta (2016) provide a ratio of 1:1 for the year 2012. The two studies just chose a typical study area in the Ten Kongduis and didn't study the temporal change of wind erosion as well.

The objectives of this paper are to reveal the interseasonal and interannual changes and spatial variations in the amount of aeolian sediment input to the Ten Kongduis and to figure out the mechanism of sediment erosion in the desert reaches of the kongduis through an empirical investigation. This research can provide some references for the sand-fixation projects built by the local governments and for researchers interested in aeolian erosion in the rivers across the deserts.

2. Materials and methodology

2.1. Study area

This study was conducted in the Ten Kongduis tributaries of the upper Yellow River (Fig. 1). These tributaries are nearly parallel to each other, and flow from south to north and drain into the Yellow River.

The Ten Kongduis have a temperate continental monsoon climate and belong to the eastern Ordos Plateau desert region in the physical regionalization of China (YRIHR, 2009). The average annual temperature ranges from 6.1 °C to 6.6 °C in the northern Kubuqi Desert and the annual evaporation is 2200 mm. The average annual precipitation ranges from only 200 mm to 400 mm, decreasing gradually from the east to the west and it is the least in the Kubuqi Desert. The rainfall in the Ten Kongduis appears mainly in the form of rainstorms and concentrates in the months from July to September, accounting for 71.2% of the annual precipitation. These rainstorms usually generate short-lived but high hyperconcentrated flows. Strong winds (> 17.2 m/s) and sandstorms often happen in winter and spring with an annual average frequency of 24 days and the average wind speed is 2.7 m/s (Liu, 2013). At Dalateqi weather station in the study area, the annual average frequency of the strong winds and sandstorms are 25.2 and 19.7 days, respectively. At Dongsheng weather station, they are 34.5 and 19.2 days, and at Baotou weather station, they are 46.8 and 21.6 days, respectively (YRIHR, 2009). Under the special physical conditions, the study area is a typical water-wind coupled erosion zone.

According to the extracted watersheds and drainage networks from the GDEM (http://www.gscloud.cn/) of the study area, the drainage area of each of the Ten Kongduis changes from 213 to 1301 km^2 with a total of 8269 km^2 and the stream length ranges from 37.1 to 114.7 km. The channel slope ranges from 3.59‰ to 8.09‰. In the middle reaches of the kongduis, the Kubuqi Desert is covered mainly by drifting sand dunes to the west and by semi-fixed or fixed sand dunes to the east of the mainstream of the Hantaichuan Kongdui. The stream lengths of desert reaches in the Maobula, Xiliugou and Hantaichuan Kongdui are 31.8 km, 22.4 km and 16.6 km, respectively (Yang and Shi, 2017).

2.2. TLS technology

Three segments of river-facing slopes of sand dunes beside the mainstreams of two kongduis have been monitored three times during